STATUS OF MINERAL RESOURCE INFORMATION FOR THE FORT HALL INDIAN RESERVATION, IDAHO

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Administrative Report BIA-29

1977

CONTENTS

SUMMARY AND CONCLUSIONS

Phosphate rock is the most valuable mineral commodity on the Fort Hall Indian Reservation. The Gay mine, operated by J. R. Simplot Co., has been in continuous operation since 1946, and is the largest producer of phosphate rock in the western United States. Annual production averages about 2 million tons. The ore is hauled by rail to Pocatello, Idaho, where about 1.3 million tons are used in the Food Machinery Chemical Corporation (FMC Corp.) elemental phosphorus plant, and the remainder in the J. R. Simplot fertilizer complex. In addition, some vanadium is recovered by Kerr-McGee Corp. from the FMC slag pile.

The life of the Gay mine is estimated to be about 10 years, by which time (1987) the phosphate economically minable by current open-pit methods will be exhausted. Hence, it is important that the Fort Hall tribes have knowledge of the reservation's other resources.

The reservation's other nonmetallic mineral commodities include sand and gravel, limestone, dimension stone, quartzite (silica), volcanic ash, pumice and tuff, and diatomaceous clay. Of these, only sand and gravel are now used. The other commodities could become important if a nearby market develops. Because they are readily available outside the reservation, the economic potentials of the reservation's nonmetallics is not great.

The geologic environment on the reservation is favorable for the occurrence of fluorite. Additional prospecting may be successful in discovering this commodity.

Except for fine gold from the Snake River and Fort Hall Bottoms area, there are no reported metallic mineral occurrences on the reservation. The adjacent Fort Hall mining district was the scene of much prospecting for copper in the early 1900's, and developmental work has continued intermittently on some of the claims. Despite all the activity, only two carloads of copper ore were reportedly shipped from the district. The mineral values are very low grade, and are found in small veins and fissures.

Snake River placer gold is so fine that its recovery is extremely difficult. In most localities it could not be economically recovered.

The reservation's potential for geothermal energy has not been adequately defined but appears to be slight. Very few thermal springs are present, and the temperature of their waters is low. However, additional studies might be desirable.

The potential for oil, gas, and coal on the reservation is low. No oil and gas has been found. There are no known coal beds. Minor occurrences of peat have been reported.

INTRODUCTION

General

This report was prepared for the U.S. Bureau of Indian Affairs (BIA), by the U.S. Bureau of Mines, and the U.S. Geological Survey under an agreement to compile and summarize available information on geology, mineral and energy resources. and the potential for economic development of certain Indian lands. Sources of information included published and unpublished reports, and personal communications. No field work was done.

Acknowledgment

Special acknowledgment is made to Mr. Francis Siler, Supervisor, Real Property Management, Fort Hall Indian Agency, who supplied maps and up-to-date data on the status of the reservation's mineral commodities.

Geography

The Fort Hall Indian Reservation consists of 524,014.31 acres in Bannock, Bingham, Caribou, and Power Counties in southeastern Idaho (Figure 1). Of the total area, 224,005.78 acres are tribally owned, 257,665.73 acres are allotted lands, and 42,342.80 acres are government owned (U.S. Department of Commerce, 1974, p. 193). The tribal headquarters is at Fort Hall, about 12 miles north of Pocatello, Idaho, on U.S. Highway 91 and west of Interstate 15.

The reservation is on the northern boundary of the Basin and Range Province, adjacent to the Eastern Snake River Plain section of the Columbia Intermontane Province (Caldwell, 1970, p. 17). The major streams are the Snake, Blackfoot, and Portneuf Rivers. All other streams are tributaries to these rivers, and all drainage is into the Snake River. The Snake and Blackfoot Rivers form the reservations northern boundary. The Portneuf River and its tributaries drain the eastern and southern parts. Lesser tributaries of the Snake River are Bannock Creek, which drains the Arbon Valley, Ross Fork Creek, and Lincoln Creek.

The reservation occupies parts of the Bannock, Portneuf, Pocatello, and Deep Creek Mountain Ranges. Elevations range from 4,355 feet at the American Falls Reservoir to 8,981 feet at South Putnam Mountain in the Portneuf Range. The mountains are generally characterized by smooth, rounded slopes; however, some are more rugged at the higher elevations. Broad, smooth-floored valleys, which tend to be formed on the softer rocks, lie between the mountain ranges. These intervening steeper, more rugged ridges are formed from the harder rocks which trend north to northwestwardly. Several benches and alluvial flood plains have been formed at the base of the mountains (Mansfield, 1920, p. 15; West and Kilburn, 1963, p. D6).

The climate is semi-arid; annual precipitation at Fort Hall is about 11 inches. Precipitation is higher in the more mountainous regions (e.g., 30 inches in the Portneuf Mountains). Peak precipitation generally occurs in late winter and early spring. July and August are usually the driest months (National Oceanic and Atmospheric Administration, Climatological Data: Idaho Annual Summary, 1975).

The vegetation is typical of semi-arid climates. Sage, juniper, mountain mahogany, and grasses are present in the lowlands, meadows, and south-facing slopes. Mountain mahogany is especially abundant in areas underlain by dolomite (Mansfield, 1920, p. 22). The north-facing slopes commonly have extensive thickets of aspen and brush-type vegetation. The higher and more rugged mountainous areas, such as the North and South Putnam Mountains and Bannock Peak, have aspen, Douglas fir, lodgepole pine, and balsam (Mansfield, 1920, p. 22).

All parts of the reservation are readily accessible by numerous primary and secondary roads (Figure 1). Pocatello, Idaho's second largest city with a population of 40,036 (1970), is the area's major transportation center. Interstate 15, a major north-south route from Salt Lake City, passes through the reservation to Blackfoot and northward to Montana. U.S. Highway 91 parallels Interstate 15 and passes through Fort Hall. Interstate 15W (U.S. Highway 30) is part of the major east-west highway across southern Idaho. A hard-surfaced road parallels Bannock Creek through the Arbon Valley. Several paved roads cross the reservation northeast of Pocatello. Numerous dirt and gravel roads branch from the main ones to all parts of the reservation.

The Union Pacific Railroad provides service to the reservation. The major east-west rail route through Pocatello is part of the Portland-Omaha route. The major north-south route runs from Salt Lake City to Pocatello and northward to Butte. (U.S. Dept. of Interior and U.S. Dept. of Agriculture, 1976, p. 1-291 - 1-293). A branch line runs from Pocatello to the Gay mine.

PREVIOUS WORK

In 1913, the U.S. Geological Survey made a geologic examination of the reservation at the request of the Office of Indian Affairs to determine the extent and character of the phosphate lands (Mansfield, 1920). Later work by Mansfield (1929, 1952) in the Portneuf and Paradise Valley quadrangles supplemented his earlier work.

Field parties of the U.S. Geological Survey actively studied the phosphate formation in southeastern Idaho, starting in the late 1940's, and prepared many reports concerning this work (McKelvey, 1949; McKelvey and Carswell, 1967; and McKelvey and others, 1967). The small percentage of uranium known to occur in the phosphate beds was of increasing interest in the phosphate study.

The history, development, and reserves of the phosphate industry on the Fort Hall Indian Reservation are discussed in U.S. Bureau of Mines reports by Service (1966, 1967a, 1967b). Schmitt (1967) described the Gay mine, an important producer of phosphate on the reservation. Trimble and Carr (1976a, 1976b) mapped the southwestern part of the reservation.

General geologic studies and regional mapping are continuing in the northeastern part of the reservation (Sando and others, 1976), and will probably result in redefinition of some elements of the stratigraphy and structure that were originally defined by Mansfield.

Topographic maps are available for all parts of the reservation (Figure 2) at a scale of either 1:24,000 or 1:62,500.

GEOLOGY

General

Outcropping rocks on the reservation range in age from Precambrian to Quaternary (Figure 3). Predominantly, Paleozoic rocks are in the southwestern part and Late Paleozoic and Mesozoic rocks are in the northeastern part. Rocks of Tertiary age, mainly volcanic, border the Snake River Plains and also form widely scattered erosional remnants on the Paleozoic rocks. The Snake River Plain is composed largely of Quaternary alluvium, volcanic sands, and remnants of basalt flows.

Paleozoic and Mesozoic rocks in the northeastern part have been folded and faulted; overturned folds are common. Much of the Paleozoic rocks in the southwestern area are part of the upper plate of a major thrust fault. North-trending normal faults have formed grabens and horsts south of the Snake River. The Snake River Plain is probably a northeast trending graben. Tertiary and younger rocks have been cut by faults but are only gently folded, if at all.

Stratigraphy

General

Mansfield (1920) was the first to establish the stratigraphy of the reservation; the main emphasis of his work, however, was in the northeastern part. Trimble and Carr (1976a, 1976b) established the stratigraphy in the southwestern part. The stratigraphic sequences in the two areas are listed on Table 1.

Southwestern Area

General

Figure 4 depicts the general distribution of rock units of different ages and the main structural features in the southwestern part of the reservation. Precambrian outcrops are north of the area in Figure 4.

Precambrian

General

Precambrian units mapped within the reservation include Papoose Creek Formation, Caddy Canyon Quartzite, and Mutual Formation, all of Upper Precambrian age. These units formerly were mapped as part of the Brigham Quartzite of Cambrian age (Anderson, 1928; Ludlum, 1942).

Papoose Creek Formation

The Papoose Creek Formation is mainly a distinctive irregularly banded gray and reddish-brown quartzite and siltite. Bedding is greatly distorted, probably as a result of intraformational deformation. The unit ranges from 600 to more than 2,500 feet thick.

Caddy Canyon Quartzite

This formerly was the lowermost unit in the Brigham Quartzite (Trimble and Carr, 1976, p. 21). The lower part consists of light colored vitreous orthoquartzite and interbedded green argillite or siltite. The presence of argillaceous interbeds serves to distinguish it from the Camelback Mountain Quartzite of Early Cambrian age. Dolomite or limestone, about 50 feet thick, occurs near the middle of the unit. Above the dolomite are pink to purplish-gray quartzite and argillite beds.

Inkom Formation

In the normal sequence, the Inkom Formation overlies the Caddy Canyon Quartzite; however, the Inkom Formation does not crop out in the Fort Hall Indian Reservation, in part because of faulting (the Inkom crops out near the reservation boundary in SE¼ sec. 37, T. 7 S., R. 33 E.)

The lower part is mainly green phyllite and grades upward to greenish-gray argillite or slate, siltite, and fine-grained quartzite. Contains a few beds of conglomerate or dirty quartzite, some of which is micaceous. Thickness ranges from 850 to 2,300 feet.

Mutual Formation

The Mutual Formation is mainly quartzite but contains conglomerate, argillite, and slate beds. Crossbedding is common. The quartzite is light gray to dark grayish-red and purple. The argillite is mainly red to dark red, and locally green. Formation is 2,500 to 3,000 feet thick.

Cambrian System

Camelback Mountain Quartzite

Only the upper part of the formation is exposed on the Fort Hall Indian Reservation but the unit is 3,500 feet thick near Pocatello. The Camelback Mountain Quartzite is a medium-grained orthoquartzite that weathers tan to rusty brown; it is mainly thick-bedded to massive and is locally crossbedded. It probably underlies the pediment gravel near the SE corner sec. 1, T. 8 S., R. 33 E.

Gibson Jack Formation

Three members of the Gibson Jack Formation are known but only the oldest member, A, is on the Fort Hall Indian Reservation. The mapped outcrop is along the east boundary sec. 1, T. 8S., R. 33 E.; pediment gravel probably overlies westward extension of this outcrop. The lower 30 feet of the member is quartzite and sandstone with interbeds of purple, brown, and tan siltstone. The rest of the unit is argillaceous siltstone that is mostly tan or gray green, although a few beds are purple or brown. Some beds are micaceous. The unit is 365 feet thick where mapped east of reservation in sec. 7, T. 8 S., R. 34 E. (Trimble and Carr, 1976a, p. 11).

Elkhead Limestone

A small exposure of Elkhead Limestone is in sec. 24, T. 7 S., R. 33 E. (Trimble and Carr, 1976a, pl. I). The formation is composed predominantly of limestone except for about 100 feet of shale several hundred feet above the base. Total thickness of the formation is about 2,100 feet. The lower part is thin-bedded, ledge-forming, and platy; the upper two-thirds is thick-bedded to massive, gray, oolitic limestone. The age of the formation, based on fossils in the shale unit, is Middle Cambrian.

Bloomington Formation

The Bloomington Formation crops out in secs. 25 and 26, T. 8 S., R. 33 E., and is a sequence of interbedded shale and limestone. The limestone is oolitic, gray to blue-gray, and is interbedded with green to olive-drab shale, argillite, and siltstone. A brown to reddish-brown, medium-grained quartzite about 80 feet thick occurs about 700 feet above the base. Total thickness is about 1,800 feet.

Nounan Dolomite

Outcrops of Nounan Dolomite have been mapped in secs. 14, 29, 32, and 35, T. 8 S., R. 33 E. The lower 135 feet is gray to blue-gray limestone and sandy dolomite, thin-bedded and oolitic in part. This is overlain by more than 80 feet of fine-grained sandstone, and above that is 100 feet of thin-bedded oolitic limestone overlain by more than 200 feet of limestone and dolomite, some of which is distinctive pale pink to pinkish gray. Total thickness of the formation is about 550 feet.

St. Charles Formation

The St. Charles Formation consists of two members, the Worm Creek Quartzite Member and an Upper Member. The Worm Creek Member crops out on Flatiron Hill in sec. 14, and in secs. 28, 39, and 36, T. R S., R. 33 E.

The Worm Creek Quartzite Member is about 1,300 feet thick. The lower 400 feet contains feldspathic crossbedded sandstone and sandy and silty gray dolomite. The rest of the member is tan fine- to medium-grained quartzite.

The Upper Member is about 200 feet thick and is mostly gray, medium bedded, cherty dolomite. Algal pisolites are common.

Ordovician System

Garden City Formation

The Garden City Formation crops out in parts of secs. 24, 25, 28, 30, 32, 33, and 36, T. 8 S., R. 33 E., and questionably in sec. 11, T. 9 S., R. 33 E. The formation, about 1,200 feet thick, is mainly blue-gray fine to medium-grained slabby limestone. Much intraformational conglomerate occurs in the lower 500 feet, layered black chert is in the upper l00 feet. The limestone has been partially dolomitized in some places.

Swan Peak Quartzite

The Swan Peak Quartzite crops out in secs. 23, 24, and 25, T. 8 S., R. 33 E., and in secs. 11, 14, 26, 28, and 33, T. 9 S., R. 32 E. The basal zone is about 30 feet of quartzitic siltstone and chloritic shale; the rest is massive to thick-bedded white to yellowish-tan quartzite except for slightly dolomitic sandstone in the upper 10 feet. Thickness is about 1,000 feet.

Fish Haven Dolomite

The Fish Haven Dolomite crops out east of Bannock Creek in secs. 23 and 26, T. 8 S., R. 33 E., and in secs. 11, 14, 25, 26, and 35, T. 9 S., R. 33 E. On the slopes on White Quartz Mountain the formation crops out in secs. 23, 27, 28, and 33., T. 9 S., R. 32 E. The lower half of the formation is medium-gray, fine- to medium-grained dolomite that locally contains chert nodules and forms conspicuous ledges. The upper half consists of a lower unit of gray dolomite and an upper unit of mottled gray dolomite. Measured thickness is about 870 feet.

Silurian System

Laketown Dolomite

The main areas of outcrop east of Bannock Creek are in secs. 1, 12, 13, 14, 23, and 36, T. 9 S., R. 33 E. In the Deep Creek Mountains the main outcrop areas are in secs. 12, 13, 19, 27, 28, and 30, T. 9 S., R. 32 E. Nearly all of the formation is uniform light-gray medium-grained dolomite. Thickness is about 1,140 feet.

Devonian System

Hyrum Dolomite

East of Bannock Creek the Hyrum Dolomite crops out in sec. 23, T. 9 S., R. 33 E; west of Bannock Creek and mainly in the Deep Creek Mountains, the formation crops out in secs. 25, 27, 28, 30, 31, 33, and 34, T. 9 S., R. 32 E. There is a small outcrop in sec. 7, T. 9 S., R. 33 E. The Hyrum Dolomite is mainly dark-gray to black dolomite, and locally contains some intraformational breccia. Thickness is about 540 feet.

Beirdneau Formation

The Beirdneau Formation crops out east of Bannock Creek in secs. 1 and 2, and in a rather continuous zone from SE¼ sec. 12 to NW¼ sec. 33, T. 9 S., R. 33 E. In Deep Creek Mountains the main outcrops are in secs. 7, 13, 19, 24, 26, 27, 28, 30, and 34, T. 8 S., R. 32 E. The formation consists of dolomitic sandstone, quartzite, bluish-gray dolomite, and minor limestone. Thickness is about 360 feet.

Mississippian System

Lodgepole Limestone

East of Bannock Creek the Lodgepole Limestone crops out in secs. 1, 2, 13, 14, 23, and 24, T. 9 S., R. 33 E. In the Deep Creek Mountains the formations crops out in secs. 13, 24, 25, 27, and 34. The thickness is variable; east of Bannock Creek it may be as much as 1,000 feet; in the saddle west of Bannock Peak (NE¼ sec. 33, T. 9 S., R. 32 E.) it is only a few tens of feet thick. In most places the formation is gray to black limestone that weathers gray to brownish gray and locally is abundantly fossiliferous. Chert is abundant east of Bannock Creek, particularly near the base and top of the formation.

Deep Creek Formation

The Deep Creek Formation is divided into a lower siltstone member and an upper chert-banded limestone. Outcrops of the formation east of Bannock Creek are in secs. 33, 35, and 36, T. 8 S., R. 33 E., and in secs. 1, 2, 23, and 24, T. 9 S., R. 33 E. In the Deep Creek Mountains the formation crops out in secs. 7, 13, 18, 19, and 30, T. 9 S., R. 33 E., and in secs. 25, 27, 28, and 34, T. 9 S., R. 32 E. Locally the upper unit becomes silty and sandy.

The lower member is as much as 760 feet thick and the upper member is as much as 1,500 feet thick.

Great Blue Limestone

The Great Blue Limestone is divided into upper and lower limestone members separated by a thick middle shale member. East of Bannock Creek and north of the Deep Creek Mountains outcrops have been mapped in secs. 31 and 36, T. 8 S., R. 33 E., and secs. 1, 2, 5, and 8, T. 9 ., R. 33 E. In the Deep Creek Mountains the formation crops out in secs. 17, 18, 19, and 20, T. 9 S., R. 33 E., and in secs. 25 and 26, T. 9 S., R. 32 E. On the west side of Deep Creek Mountains, west of the reservation, the formation is about 2,500 feet thick. The lower limestone member is light gray to gray or blue gray, medium- to coarse-grained, and massive to thick bedded. Above this is 400 feet of gray, black, brown, or greenish-gray shale, that contains a few thin beds of quartzite and abundant limestone concretions. The upper limestone member is about 850 feet thick and is thin-bedded, light gray to dark gray, and cherty. The entire formation is abundantly fossiliferous in the Deep Creek Mountains.

Mississippian and Pennsylvanian Systems

Manning Canyon Shale

The only mapped outcrop of the Manning Canyon Shale is in the S½ sec. 26, T. 9 S., R. 32 E. on the east slopes of Bannock Peak. It consists of dark-gray to black varicolored shale and argillite interbedded with limestone, siltstone, sandstone, and quartzite. Some thin beds, commonly less than 18 inches thick, in the lower part are phosphatic and contain as much as 30 percent P_2O_5 (Trimble and Carr, 1976b, p. 28 and 97). Coral and brachiopod fossils of the Manning Canyon Shale in the Deep Creek Mountains suggest that the Mississippian-Pennsylvanian boundary is about 400 feet below the top of the formation (Trimble and Carr, 1976b, p. 29).

Pennsylvanian and Permian Systems

Oquirrh Formation

The Oquirrh Formation forms the main part of the Deep Creek Mountains, of which only the northeastern part extends into the Fort Hall Reservation. Trimble and Carr (1965b, p. 29-33) divided the Oquirrh Formation into four mappable units: (1) a lower sandy limestone, (2) sandy limestone, (3) upper limestone, and (4) a cherty unit. The lower limestone unit is more than 2,000 feet thick; the sandy limestone unit is about 800 feet thick; the upper limestone unit is nearly 2,000 feet thick, and the cherty unit is about 1,100 feet thick. The lower 5,200 feet is of Pennsylvanian age and the upper 700 feet is of Permian age (Trimble and Carr, 1976a, p. 32).

Tertiary Rocks

Starlight Formation

The Starlight Formation, of Pliocene age, crops out in Arbon Valley and west of Bannock Creek; it fills intermontane valleys and laps onto the Paleozoic and older rocks of the mountains. West of Bannock Creek it crops out mainly above an altitude of 4,750 feet and extends to an altitude of as much as 6,200 feet. The total thickness is unknown but it is at least 800 feet in some areas. Trimble and Carr (1976a, p. 37-47) have divided the formation into three members: (1) the upper member is mainly bedded friable rhyolite tuff, (2) the middle member is a thick ash-flow tuff, and (3) the lower member is mainly bedded friable rhyolitic tuff with numerous marl beds and basalt flows. The formation is at least in part correlative with the Salt Lake Formation (Trimble and Carr, 1976a, p. 43).

The lower member contains many basalt flows underlain by tuff and breccia. The main outcrops of basalt extend NNE from sec. 27 to the NE¼ sec. 12, T. 8 S., R. 32 E. Basaltic tuff outcrops are mainly west of Bannock Creek. Rhyolitic tuff extends across broad areas east of Bannock Creek and forms widely scattered outcrops west of the creek. Most of this member is obscured by loess of Quaternary age. Total thickness of the member is about 500 feet.

The middle member consists of ash-flow tuffs and minor bedded air-fall tuff. The tuff is light gray to tan, poorly to well indurated, and rhyolitic. Locally the unit consists of two ash-flow units separated by 8-10 inches of quartz crystals and biotite in a matrix of glass shards. Maximum thickness of the unit is about 100 feet but in most places it is thinner.

Most of the upper member consists of white, parallel-bedded, friable rhyolitic tuff, but it also contains massive pumiceous tuff, breccia, and marl. Conglomerate, crossbedded and moderately indurated, and containing pebbles and cobbles of chert, quartzite, and rarely weathered pebbles of the middle member tuff, crops out near the southeast corner of the southwestern part of the reservation. Total thickness of the upper unit is at least 200 feet.

Quaternary and Tertiary Rocks

Widely scattered outcrops of basalt may be equivalent to the Massacre Volcanics. The basalt flows are generally thin, mostly between 5 and 30 feet thick.

Quaternary Rocks

Pediment Gravel

Coarse gravel forms widespread aprons at the base of the mountains both east and west of Bannock Creek. The gravel is bouldery near the base of the mountains and decreases in size away from tile mountains. Locally the gravel mantles a pediment surface but elsewhere it rests on either bedded silt or directly on rocks of the Starlight Formation. Thickness locally exceeds 100 feet.

Loess

Calcareous silt, probably of eolian origin, mantles Tertiary and Paleozoic rocks in much of the southwestern part of the reservation. It is light tan, poorly indurated uniform silt that is very well sorted and contains about 20 percent calcium carbonate. The loess stands in steep slopes locally, owing mainly to surficial "case hardening" or induration.

Alluvium

Alluvial deposits cover the bottom of the valleys of Bannock Creek and its tributaries and consists mainly of sand, silt, or clay.

Northeastern Part of Reservation

General

The following descriptions and discussion is abstracted mainly from Mansfield (1920). Precise correlation of some of the units here with those in the southwestern part of the reservation is uncertain. The geology of the area is currently being recompiled on 2º sheets by the USGS. Generalized distribution of the units are shown on Figure 5.

Cambrian System

The Brigham Quartzite forms much of the exposed rocks in the country around North Putnam and South Putnam Mountains in Tps. 5 and 6 S., R. 37 E. It is predominantly dense, vitreous, iron-stained, reddish or purplish, quartzite that locally is gritty or conglomeratic. It is probably more than 1,000 feet thick.

The Blacksmith Formation, a gray arenaceous limestone, is represented in several places. The Bloomington Formation, a bluish-gray, thin-bedded limestone interbedded with shales, is exposed in sec. 11, T. 5 S., R. 36 E. The St. Charles Formation, a cherty gray limestone, is represented by outcrops in T. 4 S., R. 26 E., and on the north side of Mount Putnam in T. 5 S., R. 37 E. A sandstone associated with the limestone may represent the Worm Creek Quartzite Member.

Ordovician System

Garden City Limestone

Mansfield (1920) did not differentiate this unit on the map from the Upper Cambrian rocks. However fossils from the unit have been collected from outcrops in the SE¼NW¼ sec. 27, T. 4 S., R. 36 E., and the NW¼SW¼ sec. 23, T. 4 S., R. 36 E. The limestone is dark-gray, contains much chert, and weathers to rough surface, the chert becomes reddish gray.

Swan Peak Quartzite

The Swan Peak Quartzite forms widely scattered outcrop areas on the north and east slopes of North Putnam Mountain and in secs 14 and 23, T. 5 S., R. 35 E., and secs. 26 and 35, T. 4 S.3 R. 36 E. It is white vitreous quartzite, uniform in character, and only rarely conglomerate. It is a conspicuous cliff maker and forms rugged topography. Estimated thickness is about 500 feet. The base of the unit marks the trace of the Putnam Thrust fault in many areas.

Fish Haven Dolomite

The Fish Haven Dolomite consists of cherty dark-gray limestone that weathers light gray or brown with a purplish tinge. The top of the formation has not been recognized in this area and the thickness has not been measured.

Devonian System

Mansfield (1920) mapped an area of Three Forks(?) and Jefferson limestone in the SE¼ sec. 12, T. 4 S., R. 36 E. The rocks are described as massive bluish-gray, and dense fine-grained limestones. No thicknesses were determined. The outcrop area in sec. 12 is cut by many vertical faults.

Mississippian System

Madison Limestone

The Madison Limestone crops out in several widely separated areas, including the rocky hill in the NW¼ sec. 18, T. 4 S., R. 37 E. and several places on the ridge in the west of T. 5 S., R. 38 E. It is a relatively thin-bedded, dark-bluish gray limestone, that forms beds 1 to 8 inches thick, with intervening shaly beds 3 to 6 inches thick. Fossils are numerous. The top and base of the formation have not been recognized, and the thickness cannot be determined.

Brazer Limestone

The Brazer Limestone is associated with the Madison at several localities and consists of massive dark-gray to light-gray limestone with streaks and nodules of chert in some areas. Locally the rock is finely crystalline and rich in crinoid stems. The thickness of the formation has not been determined in the northeastern part of the reservation.

Pennsylvanian System

Wells Formation

A large area in the central and northwest part of T. 4 S., R. 37 E. is underlain by the Wells Formation. Smaller outcrop areas are in the southeast corner of the reservation. Generally the Wells Formation consists of three fairly well defined units--a limestone below and at the top, with sandstones and quartzites in the middle. The entire formation is highly siliceous. The lower limestone is about 2,000 feet thick and contains massive cherty limestones and some alternating beds of sandstone or quartzite. The middle unit is 200 to 400 feet thick and is largely concealed beneath weathered slopes and younger deposits. The upper unit, about 50 feet thick, is light gray and contains chert bands as much as 6 inches thick. Fossils occur through but are more abundant in the lower limestone.

Permian System

Park City Formation

Grandeur Member.--Schmitt (1967) has shown the Grandeur Member of the Park City Formation underlying the Meade Peak Member of the Phosphoria Formation as being limestone. Schwarze (1967) designates the Grandeur Member as dolomitic limestone, light tan to blue-gray, thick-bedded to massive. The Grandeur Member is too thin to show on regional maps and its actual distribution cannot be determined from published maps.

Phosphoria Formation

General.--The main areas of outcrop of the Phosphoria Formation are in secs. 2, 11, 14, 22, T. 4 S., R. 37 E., secs. 29, 30, 31, and 32, T. 4 S., R. 38 E., and secs. 17, 18, 35, and 36, T. 5 S., R. 38 E. The formation consists of the cherty shale member (formerly called the Rex Chert Member) and the underlying Meade Peak Phosphatic Shale Member (McKelvey and others, 1967).

Meade Peak Phosphatic Shale Member.--At the Gay mine, the Meade Peak Phosphatic Shale Member can be divided into 9 mappable units as follows according to Schmitt (1967, p. 196-198).

Top	(9)	Upper siltstone	12 to 25 feet thick
	(8)	Upper Phosphatic mudstone Phosphatic mudstone and interbedded limestone averaging 13 to 17 percent P_2O_5. At top is 4 feet of phosphorate averaging about 26 percent P_2O_5. At the base of the unit is 4-foot section averaging 22-26 percent P_2O_5 ("buckshot").	30 to 40 feet thick
	(7)	Middle Siltstone Can be recognized by its banding and tan color. Contains 1.5-foot thick bed of phosphorate.	22 feet thick
	(6)	Lower Phosphatic Mudstone Averages 14 to 20 percent phosphate. Black carbonaceous mudstone, 0.2 feet thick occurs about 6 to 8 feet above base of unit.	30 feet thick
	(5)	False Cap Rock Hard white, fossiliferous dolomitic limestone or soft clay.	3 inches to 3.5 feet thick
	(4)	Phosphatic Shale Averages about 22 to 27 percent P_2O_5. 2.5 feet of argillaceous limestone about 13 feet above base. Upper 1.5 feet of unit consists of thin beds of cherty phosphorate containing as much as 32 percent P_2O_5.	17 to 24 feet thick
	(3)	Cap Rock If upper 3 feet is weathered, it may contain 23 percent P_2O_5.	Ranges from 1 ft of clay to as much as 6 ft of hard, fossiliferous dolomitic and argillaceous limestone.
	(2)	Main or "A" Bed Oolitic phosphorate	3 to 6 feet thick
Bottom	(1)	Footwall Interbedded siliceous limestone and black chert overlain by 2 to 5 feet of siltstone	11 to 14 feet thick

The phosphate-bearing mineral is a carbonate fluorapatite. Other minerals present are calcite, dolomite, fluorite, gypsum, quartz, and limonite, with organic material and clay. Weathering of the phosphate beds tends to leach carbonates and organic matter, thereby enriching the P_2O_5 content. The phosphorites are hard and dark brown or black where fresh but are often friable and range from brown to light gray, buff, or pink where weathered. Nearly all the phosphatic beds are uraniferous but the uranium content is low, ranging from -.001 to 0.065 percent (McKelvey and Carswell, 1967). In Wyoming some of the phosphatic shales are known to contain vanadium and smaller amounts of selenium, molybdenum, zinc, nickel, cobalt, titanium, and cadmium; these elements are probably also in the phosphatic rocks on the Fort Hall Indian Reservation (Love, 1967). Altschuler and others (1967) suggest that because of the immense quantities of phosphate rock dissolved in fertilizer production, the small percentages of rare-earths in the phosphate rock could cumulatively amount to a significant economic quantity if recovered.

Cherty Shale Member.--Very resistant chert with some interbedded mudstone, phosphorate, and carbonates. On the Fort Hall Reservation it is about 500 feet thick. The chert is mostly thin-bedded and argillaceous; the mudstone is harder than that of the Meade Peak Phosphatic Shale Member as it is more siliceous and probably less carbonaceous (McKelvey and others, 1967, p. 33).

Triassic System

General

The Triassic System is well represented in the northeastern part of the Fort Hall Reservation. Five formations, aggregating 5,535 feet in thickness, have been assigned to the Early Triassic and are called the Dinwoody Formation, Ross Fork Limestone, Fort Hall Formation, Portneuf Limestone and Timothy Sandstone. The Ross Fork Limestone, Fort Hall Formation, and Portneuf limestone are assigned to the Thaynes Group. Unconformably above the Timothy Sandstone is the Higham Grit, overlain by the Deadwood Limestone, and Wood Shale; these three formations, with a combined thickness of 900 feet, are doubtfully classified as Triassic. All these units are combined as Triassic undivided on Figure 5.

Dinwoody Formation

The Dinwoody Formation is composed mainly of yellow and olive drab, platy, calcareous and sandy shale which contains thin beds of gray dense limestones that weather brown or purplish. Total thickness is about 900 feet.

Ross Fork Limestone

The lower 50 feet consists of gray to reddish brown limestone containing numerous ammonite fossils and is referred to by Mansfield (1920, p. 47) as the Meekoceras zone. Above this is about 800 feet of massively bedded and thin-bedded gray to brown limestone which contains abundant brachiopod fossils. The upper 500 feet consists of dense, calcareous, gray to olive-green slate that weathers brown to yellow and is mainly unfossiliferous.

Fort Hall Formation

The Fort Hall Formation consists of four fairly well defined subdivisions: (1) the base is soft, yellow calcareous sandstone about 50 feet thick and sparingly fossiliferous; at one place it contains a limestone about 15 feet thick that contains abundant molluscan fossils; and (2) above the sandstone is about 100 feet of gray or yellowish-gray, siliceous, dense limestone with irregular cherty nodules and large pelecypod fossils; (3) sandy and shaly gray limestone about 50 feet thick, containing an oolitic bed 6 to 10 feet thick; (4) the upper part, about 600 feet thick, consists of yellow to gray cherty and sandy limestones.

Portneuf Limestone

The Portneuf Limestone consists of massive, siliceous, limestone containing nodules and streaks of chert. It forms low broad ridges and sloping interfluvial areas. The thickness is about 1,500 feet but is uncertain because of complex structure. Silicified molluscan fossils are common and project from weathered surfaces.

Timothy Sandstone

The Timothy Sandstone is mainly yellowish-gray sandstone that locally weathers pinkish-gray, and occurs in beds 1 to 3 inches thick; thickness is about 800 feet.

Triassic(?)

Higham Grit

The Higham Grit consists of about 500 feet of white to pinkish-gray, gritty or conglomeratic sandstone that forms conspicuous craggy ledges. Pebbles are mainly quartzite.

Deadman Limestone

The Deadman Limestone consists of about 150 feet of unfossiliferous dense, purplish-gray, fine-grained to lithographic limestone that contains some gray and greenish-gray chert. The rock is topographically resistant and forms conspicuous ledges.

Wood Shale

The Wood Shale crops out adjacent to the Deadman Shale and has been mapped in the same general area, even though outcrops are poor. The outcrop can be traced by the reddish soil formed from the weathering of the bright-red shale that forms most of the unit. Fragments of gypsum are found locally on the weathered outcrop. Thickness is 200 to 250 feet.

Jurassic System

Nugget Sandstone

In some places the Nugget Sandstone consists of brick-red, fine-grained sandstone in beds 1 to 6 inches thick that locally is strongly crossbedded. In other places the sandstone is more firmly cemented, coarser-grained, quartzitic, and pinkish to white. Estimated thickness of the unit is not less than 1,500 feet.

Twin Creek Limestone

The Twin Creek Limestone can be divided into three parts: (1) yellow calcareous sandstone with interbedded gray limestones crowded with oyster shells at the base; (2) thin-bedded, shaly, gray and darker limestone that weathers into chips and splintery fragments; and (3) yellow and gray calcareous thin-bedded sandstone, more or less fossiliferous, with some massive gray limestone. Thickness is probably between 2,500 and 3,000 feet.

Tertiary Rocks

Salt Lake Formation

The Salt Lake Formation consists of beds of white marl, dense yellowish-gray limestone, light-colored conglomerates, greenish clays and dark shales, and beds of white volcanic ash with yellow tuff or beds of partly waterworn volcanic debris. The formation covers many of the lower hills, forms broad sloping benches that descend from the higher hills, and occupies much of the broader valley country. Thickness has not been determined; on the higher slopes it is comparatively thin but at lower altitudes it may amount to several hundred feet.

Undifferentiated Tertiary and Quaternary Rocks

Great alluvial fans cover much of the bench lands and are composed of volcanic ash, hill wash, etc. These are not easily distinguished from the Salt Lake Formation and have been mapped as Tertiary and Quaternary.

Quaternary System

These rocks include older alluvium, recent alluvium, and travertine. The more recent deposits occupy the present flood plain of the Snake River and its larger tributaries. Travertine deposits are in the SW¼ sec. 33, T. 4 S., R. 38 E., and the SE¼SE¼ sec. 28, T. 4 S., R. 38 E., and are associated with basalt.

Snake River Plain Area

The Snake River Plain was probably an area of subsidence starting in early Tertiary time (Trimble and Carr, 1976b, p. 69 and 73) and is now essentially a northeast-trending graben on and adjacent to the Fort Hall Indian Reservation. Volcanism, perhaps related to the subsidence of the graben, erupted huge volumes of silicic air-fall tuffs and ash flows.

The tremendous accumulation interrupted the drainage and formed lakes into which some of the tuff was deposited. Later, more mafic eruptions deposited andesite and basalt on the tuffs. Pleistocene lacustrine deposits, gravel, terrace deposits, and dune sand, related in part to the catastrophic flood waters from the spillover of Lake Bonneville, are some of the youngest bedrock units. Recent alluvium forms a veneer over much of this material (Trimble and Carr, 1976b, p. 51).

Structure

General

The Fort Hall Indian Reservation is centrally located in what is known as the overthrust belt. Three large scale features dominate the structural geology. One is a large klippe that contains Paleozoic rocks which have been transported eastward for tens of miles (Trimble and Carr, 1976a) (Figure 6). Second are several east-trending tear faults which have offset the trace of the underlying thrust fault. North-trending grabens have down-dropped parts of the klippe. The third large-scale structural feature is the Snake River Plain, a northeast-trending graben that has been filled with Tertiary and Quaternary volcanic and sedimentary rocks. Smaller-scale, but important, structural features are normal faults that have broken much of the Paleozoic rock units in the southwestern part of the reservation, and open to overturned folds that have involved the Mesozoic and older rocks in the northeastern part of the reservation (Mansfield, 1920) (Figure 4 and Figure 5).

Klippe

The klippe as described by Trimble and Carr (1976a and b) is bounded in the Fort Hall Reservation by the Deep Creek Mountain Thrust in the southwestern part of the reservation (Figure 4) and the Putnam Thrust in the northeastern part of the reservation (Figure 5). The west margin of the klippe is marked by Ordovician rocks resting on Pennsylvanian and Permian rocks in the Deep Creek Mountains. In the northeastern part of the reservation the margin of the klippe is marked by Ordovician rocks thrust over Cambrian rocks (Mansfield, 1920). The pattern of tear faults offsetting the main thrust in the southwestern part of the reservation can be extended into the northeastern part of the reservation (Trimble, 1976, oral commun.).

Grabens

The valley through which Bannock Creek flows is a north-trending graben bounded on the east and west sides by normal faults of large displacement. This valley, called the Arbon Valley in its southern extension, is of the basin-and-range type (Trimble and Carr, 1976a, p. 91). Movement along the bounding faults was largely completed prior to the deposition of the Tertiary volcanic rocks that partly fill the valleys.

Kirkham (1931) suggested that the Snake River plain is a downwarp but Trimble and Carr (1976a, p. 91) interpret it as being a graben because of the abrupt termination of the mountain ranges both north and south of the plain. The Snake River Plain graben truncates the basin and range faults bounding the valleys south of the plain.

Some reactivation of movement on the basin-and-range faults is indicated by the many faults of small displacement that break the Tertiary and Quaternary rocks.

Folded Rocks in the Northeastern Part of the Reservation

Mansfield (1920) carefully mapped the Phosphoria Formation and adjacent rocks in the northeastern part of the reservation and shows, in cross sections, several open and overturned folds. Almost without exception their axes dip to the southwest. Associated with these overturned folds are several thrust faults that presumably branch upward from the main thrust surface that forms the sole of the klippe. Detailed mapping of the Phosphoria Formation by mine geologists at the Gay mine has defined east- and northeast-trending tear faults that have offset the economically important Meade Peak Member of the Phosphoria Formation for several hundred feet (Schmitt, 1967).

Brecciated and Dolomitized Rock

Trimble and Carr (1976a, pl. I) mapped a zone of dolomitized and brecciated rock adjacent to the Deep Creek Mountain Thrust fault near the southwest corner of the Fort Hall Indian Reservation. Some of this dolomitized rock appears beneath the thrust, and some extends south along the east side of a major fault called the Warner Flat fault. No metallic ore minerals are reported to occur in this altered rock; however, it might be a favorable host rock for ore deposits.

MINERAL RESOURCES

General

By far the most important mineral resource on the Fort Hall Indian Reservation is phosphate rock. The resource has been intensively studied in southeast Idaho since Mansfield's first studies that started in 1913. The first recorded production was from a mine near Montpelier, Idaho, in 1906 (Service, 1967, p. 175). The Gay mine on the Fort Hall reservation was developed, starting in 1946, and since then it has become the largest phosphate rock producer in the western phosphate field (Service, 1967, p. 181), and provides phosphate rock for the J. R. Simplot fertilizer complex and the FMC Corp. elemental phosphorus plants, both in Pocatello, Idaho. Nearly all the phosphatic beds are slightly uraniferous, and some of the phosphatic shales contain vanadium and smaller amounts of other elements. As yet, no commodities other than elemental phosphorus and vanadium have been recovered from the phosphate rock on a commercial scale.

The Higham Grit is somewhat similar and correlative to the Chinle Formation which is uranium-bearing in other western states. Perhaps additional prospecting might find uranium concentrations in the Higham.

The Fort Hall mining district, about 9 miles east of Pocatello, was the location for shallow copper mines (Weeks and Heikes, 1908, p. 179-182); the mines were short-lived, however.

If required for local industry, non-metallic resources including sand and gravel, and dimension stone, could be obtained from abundant supplies on the reservation.

Although no fluorite deposits are known on the reservation, the geologic environment is favorable and further prospecting may be successful in finding some deposits.

Metallic Mineral Resources

No record was found of any metallic mineral occurrences on the Fort Hall Reservation. However, prospecting and development have taken place in the Fort Hall mining district, immediately adjacent to and south of the reservation (Figure 7).

During the late 1800's and early 1900's, considerable placering for fine gold was done along the Snake River, near the mouth of the Blackfort River, and in the gravel of the Fort Hall Bottoms.

Intermittent mining has been reported in the Deep Creek Mountains which lie adjacent to the southwest corner of the reservation. However, very little information about the mines and prospects in this area is available.

Fort Hall Mining District

The Fort Hall mining district was established on June 17, 1902, on land ceded from the Fort Hall Indian Reservation. It comprises all of the ceded portion of the reservation within Bannock and Caribou Counties, and is approximately 26 miles from north to south, and 30 miles from east to west (Weeks and Heikes, 1908, p. 175). The principal metal occurring in this district is copper. Minor amounts of silver, gold, and lead have been reported. Some uranium prospecting has been done.

Fort Hall Mine

The Fort Hall mine in the NW¼ sec. 34, T. 7 S., R. 35 E. (Figure 7), has been the site of the district's greatest activity. Development of this property was begun in 1902 and progressed steadily until 1911. In 1909 a 50-ton-per-day concentrator was constructed. Mansfield (1920, p. 117) reports that two carloads of ore were shipped from the property, the last in 1916. Annual assessment work was continued until 1932, and there has been intermittent activity to the present (Idaho State Mine Inspector, Annual reports, 1902-1975).

By 1911, the principal development at the Fort Hall mine consisted of a crosscut driven 4,000 feet east through several different formations of sedimentary rocks. Additional crosscuts, winzes, and raises brought the total development to more than 8,000 feet (Idaho State Mine Inspector, Annual Reports, 1902-1912).

The mineral zones at the Fort Hall mine occur in the Scout Mountain Member of the Precambrian Pocatello Formation (Trimble, 1976, pl. 1). This member is characterized primarily by thick layers of unsorted, nonstratified rock that is composed of submarine tillite, interstratified quartzite and conglomerate, minor amounts of argillite and siltite, and a few beds of limestone and dolomite (Trimble, 1976, p. 13).

Weeks and Heikes (1908, p. 181-182) gave the following description of the ore deposits at the Fort Hall mine:

> "----the ore-bearing zone comprises approximately 125 feet of crumpled and contorted layers of ore-bearing gray shale

> and thin-bedded limestone from 1 to 3 inches thick....The most abundant mineral is chalcopyrite, which occurs as veinlets. A small amount of galena is contained in the limestone. There is also some pyrite. The copper-bearing shale zone contains innumerable, mostly non-persistent veins and veinlets filled with quartz, calcite, and chalcopyrite, with smaller amounts of pyrite....These veinlets are bent, corrugated, and contorted. The shale itself is a normal clay shale with sericite in minute flakes and aggregates of dolomite. Next to the seams of quartz and chalcopyrite, sericite is developed more abundantly over a distance of a few millimeters...."

To determine proper milling methods an 11.05-ton sample was taken across a 125-foot width of the ore ton. An assay of a 1 ton concentrate from this sample gave the following results: 12.3 percent copper, 0.13 ounce gold per ton, 4.30 ounces silver per ton, 26.4 percent iron, 0.8 percent lead, and 16.1 percent silica. The gangue consisted of quartz with some calcite (Weeks and Heikes, 1908, p. 182).

There are several prospects on Papoose Creek, east of the Fort Hall claim group (Figure 7). In 1922, development consisted of a 1,600-foot crosscut driven westward through black shale (Campbell, 1922, p. 30). Copper was the metal of interest, and its occurrence is undoubtedly similar to that of the adjacent Fort Hall mine.

Moonlight and Adjacent Mines

The Moonlight mine group of claims is located about 9 miles east of Pocatello at the head of Rapid Creek, about ½ mile south of the reservation boundary in sections 17 and 18, T. 6 S., R. 36 E. (Figure 7). Development work was begun in 1902. In 1904, two 20-ton carloads of high-grade ore were shipped from the Moonlight mine. The ore reportedly averaged 25 percent copper and 14 ounces of silver per ton (Bell, 1964, p. 31). In 1916, a shipment of 9 tons, averaging 22 percent copper, 8.3 ounces silver per ton, and 0.005 ounce gold per ton, was made from material sorted from the dumps (Mansfield, 1920, p. 116).

In 1907, development at the Moonlight mine consisted of a crosscut 830 feet long, driven westward and ending in a 90-foot raise to known ore bodies. Two adits, 275 and 75 feet long, were driven near the top of the hill above the mine (Weeks and Heikes, 1908, p. 180). A crosscut was opened in 1905 on the opposite side of the mountain and was driven toward the vein. This adit attained a final length of over 500 feet (Bell, 1905, p. 26).

The ore deposits occur in the Upper Member and the Scout Mountain Member of the Precambrian Pocatello Formation (Trimble, 1976, pl. 1). The Upper Member consists of black to tan, thinly-laminated, slaty to phyllitic argillite in the lower half, and interbedded quartzite and argillite in the upper half (Trimble, 1976, p. 17-18).

Bornite, chalcocite, and copper carbonates are found in small kidney-shaped pods, fractures, and fissures in conglomerate. The fractures trend north-south and dip about 40º east (Weeks and Heikes, 1908, p. 180).

Other Prospects and Mining Activity

Dozens of mining ventures were begun in the Fort Hall mining district between 1902 and 1910, but none appear to have progressed much beyond the prospecting stage.

Extensive prospecting was done north of the Portneuf River, between Pocatello and Inkom. Copper, along with minor gold and silver, was reported at several prospects. These occurrences were in quartz veins (Idaho State Mine Inspector Annual Reports, 1902-1910).

Some uranium prospecting was done on Chinks Peak about 3 miles east of Pocatello during the uranium boom of the early 1950's (Idaho State Mine Inspector, Annual Reports, 1950-1954). Development consisted of several dozer trenches, but the property was abandoned in 1954.

Since 1958, intermittent work has been done by the Kopper King Mining Co. on several unpatented claims near Inkom. The principal mineral value is copper, with some silver, lead, and gold. Development in 1958 consisted of two adits, one 600 feet long (Idaho State Mine Inspector, Annual Reports, 1958-1975). Although the exact locations of these claims are not mentioned, the description suggests the Papoose Creek area.

Over the years prospecting has been done in the Bell Marsh Creek area (Figure 7), but no production has been reported (Idaho State Mine Inspector, Annual Reports, 1902-1975).

Weeks and Heikes (1908, p. 182-183) concluded that the ore bodies in the Fort Hall mining district were too low grade to mine. Trimble (1976, p. 79) states that "examination of scores of small prospect pits in the area has shown that a great amount of effort has been expended for no financial return."

The Scout Mountain Member of the Pocatello Formation, in which the ore deposits at both the Fort Hall mine and the Moonlight mine occur, extends across the reservation boundary into sec. 7, T. 6 S., R. 36 E., where it is in fault contact with younger rocks (Trimble, 1976, Pl. I).

Snake River Gold Placers

During the late 1800's and early 1900's the Snake River between Blackfoot and American Falls was placered for gold. From 1885 to 1936, 24,242 ounces of gold were produced from Bingham County (Staley, 1946, p. 13). However, most production was before 1910, when Bingham County included part of what is now Bonneville County, and extended to the Wyoming border. Thus the actual production of gold from that part of the Snake River adjacent to the reservation is unknown.

Placer mining took place at the following locations: Welch Ground, 1½ miles north of the mouth of the Blackfoot River; Gold Point and Eagle Bend, both of which are ¾ to 1 mile above the confluence of the Blackfoot with the Snake River; the Fort Hall Bottoms, which cover about 30,000 acres along a 24-mile stretch of the Snake River; and Horse Island, near the mouth of the Portneuf River (Hill, 1916, p. 239-291). The general locations of the placers are shown on Figure 7.

The gold is in both terrace gravel and present stream deposits; it is more abundant in fine gravel than in coarse (Hill, 1916, p. 279). The gravel contains white, cream-colored, and gray quartzite pebbles, with some dark slate, white quartz, and red and gray flint. The accompanying sand is composed primarily of quartz grains and heavy minerals. Most gravel is coarse, and composed of subrounded to rounded pebbles, ranging from ¼ inch to 4 inches in diameter. The fine gravel contains pebbles ranging from ¼ to 1 inch in diameter; it occurs in small lenses in the coarse gravel and on tops of high bars in the present river channel. It contains a large quantity of heavy mineral sands and is locally called "skim-bar" gravel. (Hill, 1916, p. 278-279).

Hill (1916, p. 280) gives the following description of the Snake River gold:

> The...gold is in minute particles, most of which are flat. The largest pieces are scarcely 0.01 inch in diameter, and the colors range from those of that size to some so small that the separate flakes can be distinguished only with a high-power microscope. The large flakes as a rule are somewhat cupped, apparently owing to the turning up of their edges by repeated knocks. Most of the microscopic colors are flat, but some are rounded, irregular grains.
>
> Most of the gold has a bright-yellow color, but certain flakes appear red-brown in some lights. In part the color of the rusty gold appears to be due to a roughened surface, but some of the larger flakes of brown color have a thin coating of brown material that is probably iron hydroxide...
>
> The gold from the Snake River is from 0.930 to 0.951 fine and averages about 0.945, according to most reports. The particles are so small that it takes from 1,000 to 2,000 colors to be worth 1 cent.

At the Welch placer, the Snake River had cut into an 18-foot gravel bank. The bank was covered by 2 to 4 feet of soil. The gravel contained gold throughout the depth exposed by the river cut. The gold, which averaged about 40 cents per cubic yard (at 20 dollars an ounce), was washed and caught in sluices and on burlap tables (Hill 1916, p. 289).

The placer gravels at Gold Point and Eagle Bend rested upon basalt. At Gold Point, the gravel, with a mean depth of 8 feet, reportedly averaged 40 cents per cubic yard (at $20 an ounce) throughout (Hill, 1916, p. 290).

The surface of the Fort Hall Bottoms is a gray to black sandy loam, which contains abundant clay in places. The gravel, which is irregularly distributed at the surface, is thought to represent the tops of buried bars, such as are found along the present channel of the Snake River (Hill, 1916, p. 290).

The gold in the gravel of the Fort Hall Bottoms averaged less than 1 cent per cubic yard (at $20 an ounce). The Snake's skim-bar gravel carried at least 65 cents per cubic yard (at $20 an ounce) and was worked each year after high water. It sometimes carried 2 to 3 dollars per cubic yard (at $20 an ounce) in gold, but formed a very minor part of the total gravel of the Fort Hall Bottoms (Hill, 1916, p. 291). Horse Island is now beneath the waters of the American Falls Reservoir. The gold bearing gravel lay beneath 2 to 8 feet of soil and followed more or less well-defined lines of crescent-shaped bars (Hill, 1916, p. 291). No record of production was found.

Hill (1916, p. 294) concluded that most of the Snake River gravel deposits contained so little gold that they could not really be called placers. He believed that some might possibly be profitable if worked on a large scale, and that a few gravel bars could possibly be worked at a profit by hand methods. However, the extremely fine nature of the gold, together with the methods of mining and extraction available in the early part of the century, made these deposits unprofitable.

Deep Creek Mountains Area Prospects

During the past 50 years several mining ventures have been attempted in the Arbon Valley south of the reservation, and in the Deep Creek Mountains and Rockland Valley areas southwest of White Quartz Mountain and Bannock Peak (Idaho State Mine Inspector, 1925-1975). The precise locations of these activities, and any production data, are not recorded in the available literature.

The Bannock Apex Mines, Inc. has held a group of claims, located about 4 miles southwest of White Quartz Mountain in T. 10 S., R. 31 E., since 1935. Lead, zinc, and silver have been the principal commodities sought. Development work consisted of several hundred feet of underground workings. There are no indications that any ore was shipped from the area (Idaho State Mine Inspector, Annual Reports, 1935-1975).

Trimble and Carr (1976, p. 97) report a small barite prospect in the SE¼NE¼ sec. 10, T. 8 S., R. 31 E., west of the reservation. Mercury was reportedly produced from prospects in the SW¼NE¼ sec. 28, T. 8 S., R. 31 E., but Trimble and Carr (1976, p. 97) found no mercury minerals in the dumps.

Nonmetallic Mineral Resources

Nonmetallic commodities occurring on or near the Fort Hall Indian Reservation are phosphate rock, sand and gravel, crushed rock, limestone, dimension stone, quartzite (silica), volcanic ash, pumice, tuff, and diatomaceous clay. The only active mining operation on the reservation is the Gay phosphate mine, operated by J. R. Simplot Co. but there are numerous sand and gravel pits north and northwest of Pocatello. Limestone is quarried at Inkom, and quartzite was quarried until recently southwest of Pocatello near the reservation boundary.

Phosphate Rock

Occurrences

Phosphate deposits on the Fort Hall Indian Reservation occur in the Phosphoria Formation of Permian age, and form only a small part of extensive deposits in southeastern Idaho, southwestern Montana, western Wyoming, and northern Utah. This area, known as the Western Phosphate Field, contains about 45 percent of the United States phosphate reserves (U.S. Dept. Interior and U.S. Dept. Agriculture, 1976, p. 2-1). Southeastern Idaho holds about 90 percent of the economically extractable deposits (Powell, 1974, p. l).

Phosphate on the Fort Hall Indian Reservation is mined at the Gay mine, 18 miles east of Fort

Hall on Pole Line Road (Figure 1). The mine is operated by J. R. Simplot Co. to provide phosphate rock for their fertilizer complex and for the FMC elemental phosphorus plant, both in Pocatello. Development at the Gay mine began in 1946, and mining has been continuous since that time. The mine is the largest phosphate rock producer in the Western Phosphate Field. The 1975 production was about 2.5 million tons with 2 million tons going to FMC Corp. and 0.5 million tons to Simplot (U.S. Dept. Interior and U.S. Dept. Agriculture, 1976, p. 1-247).

The East Gay mine about 3 miles east of the Gay mine is also operated by Simplot as a part of the same operation. This is the only phosphate mining on the reservation. Most of the potentially valuable deposits are leased by J. R. Simplot Co. and FMC Corp. (Figure 8). Large tonnages of low-grade phosphatic shales (14 to 20 percent P_2O_5) have been stockpiled for future use (Service, 1967, p. 91; Day, 1973, p. 6).

Phosphate deposits also occur near the southeastern part of the reservation (Figure 8). This area is included in what Service (1966, p. 151) described as the Chesterfield district. To date, there has been no mining here, but most deposits have been explored. The phosphate deposits occur on the west limb of the Rock Creek syncline, paralleling other folds in the district. Local folding and faulting have broken, offset, and, in places, overturned the phosphate bed. The most continuous outcrops are along Rock Creek near the reservation border. In spite of folding and faulting, Service (1966, p. 153-158) believes that the Rock Creek deposits offer the Chesterfield district's best potential for both underground and surface mining. Service recommended a detailed structural mapping program to further assess the reserve potential, which he estimated at approximately 11.5 million tons of ore of all grades that are available by surface mining methods (Service, 1966, p. 158).

Uses and Specifications

Phosphorite is a sedimentary rock composed principally of amorphous phosphate minerals. Most commonly it is a bedded marine rock composed of microcrystalline carbonate fluorapatite in the form of laminae, pellets, oolites, nodules, and skeletal and shell fragments. It is the most important source of phosphorus for fertilizers, phosphoric acid, and elemental phosphorus. The terms "phosphorite" and "phosphate rock" are used interchangeably (Service and Popoff, 1964, p. 3).

Phosphate rock products have the following applications (Service and Popoff, 1964, p. 6): Agricultural uses include fertilizers, animal feed supplement, weed killer and insecticides, and land dressing. Industrial applications include chemical (catalysts, detergents, dyes, sugar refining, leavening agent, perfumes), electrical (electric heaters, electrodes, filaments, and insulation), metallurgical (alloying, phosphating metals, rust preventatives, and cleaning agent), plastics (softening agent, films, and imitation ivory), petroleum (absorption agent, catalyst, purifier, and cracking agent), and military (incendiary shells and bombs, smoke pots, flares, and corrosion and projectile resistant steels).

The fertilizer industry expresses grade of phosphate rock by percent P_2O_5 (phosphorus pentoxide), the final product of the complete oxidation of phosphorus; BPL (bone phosphate of lime); and TPL (triphosphate of lime). The chemical and elemental phosphorus industry uses percent P (phosphorus) (Service and Popoff, 1964, p. 3; Emigh, 1975, p. 935). Phosphate fertilizers are classed as (1) water soluble, (2) citrate soluble, and (3) citrate insoluble. Available phosphoric acid (APA) and available P_2O_5 are terms used to express the amount of available phosphorus in a fertilizer product (Service and Popoff, 1964, p. 3).

The percent BPL in a material multiplied by the factor 0.458 equals the percent P_2O_5; the percent BPL multiplied by 0.20 equals the percent elemental phosphorus (P). The classification grades of Western phosphate rock and their uses are listed in Table 2.

According to Service and Popoff (1964, p. 4):

Phosphatic fertilizers are classed in two groups, basic (simple) and fixed. Basic fertilizers are:

Concentrated superphosphate	24.0 to 54.0% APA
Triple or treble superphosphate	40.0 to 48.0% APA
Ammonium phosphate	48.0 to 52.0% APA
Phosphoric acid	50.6 to 76.0% APA
Ground phosphorite 5.0 to 10.0% APA	
	28.0 to 30.0% P_2O_5

Mixed fertilizers are those containing at least two of the main plant foods, and are known by their ratio of plant nutrients: N (available nitrogen), P_2O_5 (available phosphate), and K_20 (available potassium oxide). This ratio is expressed in units of plant food, each unit equals 20 pounds or 1 percent of a ton.

Marketable phosphate rock is graded according to its BPL content in percent, current export pricing is based on a metric ton, unground, f.o.b. vessel, Tampa or Jacksonville, Florida (Stowasser, 1975, p. 820).

Grades sold are 77 to 76 percent, 75 to 74 percent, 72 to 70 percent, 70 to 68 percent, 68 to 66 percent, and 66 to 64 percent. Phosphate rock quality is affected by the iron and alumina content, and price adjustments are made if the specified limits are exceeded. A combined iron and alumina level of 3 percent for 75 to 74 percent and 77 to 76 percent BPL is acceptable. An excess, up to 4 percent iron and alumina is adjusted by deducting from the actual analysis 2 units BPL for 1 unit iron and alumina. A 4-percent maximum combined iron and alumina is acceptable for all other grades except 66 to 64 percent BPL. A 5-percent maximum combined iron and alumina is acceptable for 66 to 64 percent BPL. Although phosphate rock is sold on a bone dry basis, actual moisture is guaranteed not to exceed 3.5 percent on all grades except 66 to 64 percent BPL, which has a 5-percent maximum moisture limitation (Stowasser, 1975, p. 820-821).

TABLE 2

Grade Classification of Western Phosphate Rock

[Modified from Service and Popoff (1964, p.4) and Day (1973, p. 6)]

Grade	P_2O_5 Content	Use
#1-Acid, fertilizer, high grade (sp.gr. 2.85)	+31%	Can be used without beneficiation for the manufacture of phosphoric acid and phosphate fertilizer.
#2-Furnace-grade (sp.gr. 2.65)	24 to 31%	Can be used directly in electrical furnaces for the manufacture of elemental phosphorus.
#3-Beneficiation-grade (sp.gr. 2.47)	18 to 24%	Must be beneficiated for use in the manufacture of either phosphorus of phosphate fertilizer.
#4-Low-grade shales (submarginal) (sp.gr. 2.40)	10 to 18%	Cannot normally be economically processed at the present time.

Mining Methods

The bulk of the world's phosphate is mined by open pit. Costs are largely affected by the thickness and hardness of the overburden. Thus, larger equipment with its lower unit cost of operation, permits removal of a greater thickness of overburden (Emigh, 1975, p. 949).

> "The cost of surface mining varies from mine to mine because of variations in the depth of overburden, thickness and grade of the phosphate member, dip, faulting, grade of recovered ore, and location relative to transportation facilities or plant (Service, 1967, p. 185)."

A mine where acid, furnace, and beneficiation grade ores are being mined selectively will have higher costs than a mine having just one grade of ore. Flat dipping beds can be mined in large panels, whereas the steeper dipping beds must be mined along strike in a series of lifts progressing from one side of the section to the other. Grade control in steeply dipping beds is also more difficult than in flat beds.

The mining operation at the Gay mine is highly selective, and it necessarily must maintain close control to hold to the various grades being mined. The pit area is divided into mining panels, based on ore grade, waste to ore ratio, and the suitability of the ore far processing (Schmitt, 1967, p. 201). Preliminary drilling and sampling is done in a grid system, with spacings of approximately 100 by 300 feet (Service, 1966, p. 165). Before mining, the panel is again drilled and sampled on closer intervals to provide the detailed information necessary for mining control.

> The mining cycle at the Gay mine consists essentially of four steps (Service, 1966, p. 165): (1) Stripping overburden; (2) mining and stockpiling low-grade phosphatic shales; (3) mining furnace-grade shales; and (4) mining the main bed fertilizer-grade ore. There are several strata in the mining section that are mined individually as waste or ore. Waste is dumped on "spoil piles" where it will not interfere with future mining. Waste shales and low-grade ore are hauled to waste dumps or mill shale stockpiles..... Continuous sampling permits blending and balancing of mine-run ore to maintain a grade as close to 32 percent P_2O_5 as possible for fertilizer grade rock and 24 percent P_2O_5 for furnace grade rock. Ore is dumped on a grizzly, and undersize material is passed over vibrating screens; oversize (plus 3-inch) is sent through a jaw crusher, which reduces it to the required size before it is loaded into railroad cars. The ore is sampled as it is loaded.
>
> Overburden is removed by 28-yard, twin-engine scrapers, and end dump trucks which are loaded by a 4.5 yard shovel. The ore is loaded by 2½ and 3½ yard shovels into 35-ton capacity end dump trucks, and hauled to a crushing and loading installation, at the Gay mine. Ore from the East Gay mine has to be trucked about 3 to 5 miles to the loading site (Schmitt, 1967, p. 202).

Ore mining operations at the Gay mine are carried on for five to six months during the spring and summer. Stripping is done the year round. Stockpiles of ore are kept at the plants to assure year-round operations (Service, 1966, p. 165).

Milling and Processing Methods

Phosphate rock is commercially processed in three ways (Emigh, 1975, p. 937): (1) acidification treatment; (2) electric furnace treatment; and (3) simple physical treatment.

Acidification of phosphate rock with sulfuric acid is done to make normal superphosphate, concentrated superphosphate, phosphoric acid as a base for making ammonium phosphate fertilizers, and phosphoric acid used as a purifying agent in the production of industrial chemicals. Acidification of phosphorite with nitric acid is used to make nitric phosphate fertilizers, and with hydrochloric acid to make phosphoric acid.

Electric furnace treatment of phosphorite produces elemental phosphorus, which is usually converted to high purity phosphoric acid that is used in the production of industrial chemicals such as phosphates of sodium, calcium, potassium, and ammonia. Phosphoric acid is also called food-grade when further purified.

Phosphate rock may be treated by simple physical methods, such as fine grinding for use as a fertilizer by direct application to soils, and removal of fluorine by heat, which results in a cleaner calcium phosphate rich rock suitable for an animal feed supplement.

About 50 percent of the Western phosphate rock goes to electric furnaces without beneficiation, other than screening to remove unweathered carbonate rock and unweathered phosphorite (Emigh, 1975, p. 951). There are four benefication plants in the Western Field; one calcining, and one washing-flotation in Utah, and one washing-calcining and one washing in Idaho.

According to Service and Popoff (1964, p. 23-24), there are numerous and complex problems associated with beneficiation and flotation of Western phosphate ore. It is necessary to separate the phosphate from the accompanying deleterious material by flotation. Unwanted materials in Western rock are carbonate minerals, fluorine, silica or quartz, clays, iron, alumina, and carbonaceous matter. Some of these can be removed by scrubbing or calcining in a kiln or fluid-bed reactor. However, to upgrade low-grade shales, it is necessary to remove a major portion of the carbonate minerals which do not readily respond to known flotation schemes (Service and Popoff, 1964, p. 23-24).

The J. R. Simplot fertilizer complex processes about 300,000 tons of high-grade phosphorite (plus 31 percent P_2O_5) yearly from the Gay mine, and about 450,000 tons of sized concentrate from the company's mining-beneficiation operation at Conda, which is approximately 25 miles southeast of the reservation. The fertilizer complex includes calcining operations and plants producing sulfuric acid, ammonia, phosphoric acid, triple superphosphate, ammonium phosphate, ammonium sulfate, urea nitrate solution fertilizer, and liquid fertilizers (Dept. Interior and Dept. Agriculture, 1976, p. 1-261 - 1-263).

Each year the FMC Corp. elemental phosphorus plant at Pocatello uses about 1.8 million tons of phosphatic shale, 190,000 tons of coke, and 130,000 tons of silica. About half the coke is shipped by rail from Wyoming. The silica, in the form of quartzite pebbles and cobbles, is removed by FMC Corp. from the valley alluvium adjoining the Portneuf River near the Pocatello plant site (U.S. Dept. Interior and U.S. Dept. Agriculture, 1976, p. 1-263).

Following crushing and blending, the phosphatic shale used for furnace feed at the FMC Corp. plant has a P_2O_5 content of 24 to 25 percent. The four electric furnaces have a combined capacity of 280 to 290 million pounds annually. Most of the phosphorus produced is used in detergents, cleaning agents, and other household products, including numerous food products (U.S. Dept. Interior and U.S. Dept. Agriculture, 1976, p. 1-263 - 1-264).

Transportation

Transportation, for both crude ore and the marketable product, is one of the foremost problems in the development of phosphate deposits. Long-distance haulage of crude ore is not feasible because of the waste that must be moved per unit weight of P_2O_5; therefore, most operators prefer to haul a concentrate or marketable product.

In the Western Phosphate Field transportation has not been a serious problem because most of the mines and plants are situated near major highways and rail lines. Ore from the Gay mine is transported by rail about 30 miles to Pocatello to FMC plant stockpiles.

Marketing

In 1976 the domestic distribution of phosphate rock production was as follows: Florida and North Carolina, 84 percent; California, Idaho, Arkansas, Missouri, Montana, Utah, and Wyoming, 12 percent; and Tennessee, 4 percent. The principal markets for phosphate rock were fertilizers and animal feed supplements, 65 percent; industrial and food grade products, 13 percent; and export 22 percent. (Commodity Data Summaries, 1977, p. 124).

The world surplus of phosphate rock, which developed in the second half of 1975, continued through 1976. The competition for world phosphate rock markets eroded the selling prices from January 1976 levels of $37.55 (70 percent BPL) per metric ton, f.o.b. vessel, Tampa Range, to $29.55 (70 percent BPL) for December 1976 (Commodity Data Summaries, 1977, p. 125).

Conversion of phosphate rock to fertilizers or fertilizer intermediates increased in 1976. A surplus of phosphate fertilizers in the United States, and in the world contributed to a further decline in domestic and export prices. At the end of 1976, prices stabilized at $125 to $140 per metric ton for diammonium phosphate and $90 to $110 per metric ton for triple superphosphate (Commodity Data Summaries, 1977, p. 125).

Both the domestic and the international demand for phosphate rock is expected to increase. U.S. demand is forecast to increase at an annual rate of about 3 percent per year through 1985. World demand will probably exceed the projected rate of increase for the United States (Commodity Data Summaries, 1977, p. 125).

By-Products (Vanadium and Uranium)

Both vanadium and uranium are present in the Phosphoria Formation. Vanadium is currently being recovered by Kerr-McGee Corp. from the slag pile at the FMC Corp. elemental phosphorus plant in Pocatello. Uranium is not yet being recovered.

At the FMC Corp. plant in Pocatello, molten ferrophosphorus, a furnace residual averaging 4 to 5 percent vanadium, is collected in chill molds and custom crushed. About 15,000 tons of this material are shipped annually by rail to East Coast vanadium producers, and about 5,000 tons per year are shipped to the Kerr-McGee plant at Soda Springs, 65 miles southeast of Pocatello. Annual production of ferrophosphorus at the FMC plant is approximately 20,000 tons (U.S. Dept. Interior and U.S. Dept. Agriculture, 1976, p. 1-266).

Vanadium's chief use is as an alloying agent for iron and steel, to which it is usually added in the form of ferrovanadium or proprietary vanadium-carbon-iron products. It is also important in vanadium-aluminum master alloys prepared for additions in titanium-based alloys (Commodity Data Summaries, 1977, p. 184).

Sand, Gravel, and Crushed Rock

Sand and gravel is abundant on and near the reservation, especially northwest of Pocatello. Trimble (1976, p. 76) gives the following appraisal of the sand and gravel resources of the Michaud quadrangle which covers the northwestern part of the reservation:

> Sand and gravel has been obtained from the Michaud Gravel, gravel of the Aberdeen terrace deposits, both Holocene and older alluvial gravel of the Portneuf River, Pleistocene pediment and fanglomerate deposits, and Tertiary conglomerate. All these gravel deposits are composed of a mixture of lithologic constituents, including quartzite, limestone, and basalt, and all are essentially unweathered and sound. There is great variation in the size and cementation of the materials, however, and in degree of sorting. The most desirable sources of gravel are probably the alluvial gravels of the Portneuf River and the Aberdeen Terrace gravels, for both of these are unconsolidated and well sorted. The Michaud Gravel, east of Michaud Creek, is unconsolidated, but contains abundant large boulders and is poorly sorted. The older Pleistocene deposits and the Tertiary deposits commonly are stained and moderately cemented, but have been used as highway aggregate and road metal.

Trimble and Carr (1976, p. 96) report several abandoned pits in the older alluvium south of the Snake River near Neely, about 8 miles west of the Reservation. Coarse gravel in small quantities has been obtained for local use from the pediment gravel and the Starlight Formation.

The general availability of gravel has not favored local use of crushed rock. There are some abandoned quarries in the basalt of the Portneuf Valley near Pocatello, and large quantities of crushed rock were removed from a quarry developed in the Camelback Mountain Quartzite near Inkom (Trimble, 1976, p. 77). The Arbon Valley basalt and Paleozoic carbonate rocks have not been greatly utilized as a source of crushed rock. However, they constitute a large reserve of material that could be used for road construction or concrete aggregate (Trimble and Carr, 1976, p. 96).

Annual Reports of the Idaho State Mine Inspector (1970-1975) list several active and inactive sand and gravel quarries on and near the Fort Hall Indian Reservation in the vicinity of Pocatello. These quarries are operated by the Idaho Division of Highways, and the Bannock, Bingham, and Power County Highway departments. Most are located in the Michaud Flats and Fort Hall Bottoms areas. The general locations of several quarries are shown on Figure 7.

Sand and gravel resources on the reservation appear adequate for local needs for many years. Because the low unit value of sand and gravel necessitates sources be near the point of use, most active and inactive quarries are concentrated near Pocatello.

Limestone

Limestone is a sedimentary rock composed mostly of the mineral calcite ($CaCO_3$); dolomite is a sedimentary rock composed mainly of the mineral dolomite $CaMg(CO_3)_2$. Both are commonly called limestone by the industry, and intermediate varieties are seldom distinguished.

Numerous limestone units are present in Precambrian and Paleozoic rocks, on and near the reservation. The nearest active limestone quarry is south of the reservation near Inkom; it supplies a nearby cement plant operated by the Idaho Portland Cement Co., a division of the Oregon Portland Cement Co. According to Trimble (1976, p. 77), the quarry stone is probably part of the Middle Cambrian Elkhead Limestone. It is impure and contains shale. The entire hill, with the exception of a dolomitized fault zone east of the quarry, is being utilized.

The Inkom cement plant has a reported capacity of 949,000 barrels per year. It operates at 83 percent capacity, and utilizes 178,000 short tons of limestone, from which it produces 788,000 barrels of cement per year (Savage, 1964a, p. 116). There are sufficient raw materials, near and adjacent to the plant to supply it for many years.

The value and use of carbonate rocks are determined by their composition. High calcium limestone, which consists of at least 95 to 97 percent $CaCO_3$ by weight, has a great variety of uses in the chemical and metallurgical industries.

Provided they are uniformly distributed throughout the rock, considerable amounts of clastic impurities are acceptable in cement limestone. However, in Portland cement there must be less than 6.5 percent dolomite because raw materials for Portland cement cannot contain more than 3 percent $MgCO_3$. Portland cement may contain no more than 5 percent MgO.

Chert is undesirable in crushed stone used as concrete. The chert may react with the cement, and the resulting chemical compounds may weaken the concrete and cause spalling. Carbonate rocks containing more than 25 percent fine clastic material (as shale or siltstone?) are suitable only for fill on construction projects. (Hubbard and Erickson, 1973, p. 358).

Possible sources of limestone on the reservation are units of the Jefferson Limestone, Three Forks Limestone, Madison Limestone, Deep Creek Formation, and Wells Formation. Most of these formations contain interbedded chert, siltstone, and limestone and shale partings which lower the purity. However, some exposures probably contain limy units suitable for concrete aggregate or crushed stone for construction.

Dimension Stone

Albee (1969, personal commun. to the Fort Hall Business Council) suggested a portion of the reservation that might lend itself to a dimension stone operation. This is the area of the Nugget Sandstone (Mansfield, 1920, p. 52-53) in parts of sections 9, 10, and 15, T. 3 S., R. 37 E., north of Gold Creek (Figure 7). Trimble (1970, personal commun. to the Fort Hall Tribal Council) also recognized the Nugget Sandstone as a possible source of rock for a small building stone industry.

Mansfield (1920, p. 53) gives the following description of the Nugget Sandstone:

> "The Nugget Sandstone consists of many places of brick-red, fine-textured sandstone in beds 1 to 6 inches thick, locally strongly cross-bedded, which form rounded hills that are strewn with angular, platyblocks weathered from the ledges. In

> other places, the sandstone is somewhat firmer, coarser textured, quartzitic, and pinkish to whitish in color, weathering dark and forming slopes strewn with rough, blocky, purplish talus."

In addition to the specific areas recommended by the U.S. Geological Survey as possible sources of building stone, the Nugget Sandstone occupies about one-third of T. 3 S., R. 37 E., much of the SW¼ T. 3 S., R. 38 E., and part of the north half of T. 4 S., R. 38 F. (Mansfield, 1920, Plate III). Further investigation might reveal additional exposures suitable for building stone.

Travertine is a light-colored calcium carbonate, usually concretionary and compact, deposited from solution in ground and surface waters. Extremely porous or cellular varieties are known as calcareous tufa, calcareous sinter, or spring deposit. Travertine forms the stalactites and stalagmites of limestone caves, and the filling of some veins and hot spring conduits. Certain varieties are used as a decorative building stone.

Mansfield (1920, p. 57) reports deposits of travertine in most of the SW¼ sec. 33, T. 4 S., R. 38 E., and in the SE¼SE¼ sec. 28, T. 4 S., R. 38 E. These deposits are associated with active springs. Smaller deposits are associated with, and apparently overlie, the basalt in T. 4 S., R. 35 E.

The principal uses of dimension stone are in building construction and for monuments. Other uses include flagging, curbing, paving, millstock slate, roofing slate, laboratory furniture, and refractory brick (lower, 1975, p. 157).

Color, pattern, and texture govern the marketing potential of dimension stone. Soundness or freedom from flaws is one of the most important factors, and yet one which is very difficult to determine. Special methods are required to extract and transport dimension stone (Power, 1975, p. 173).

Because the total output of a quarry is small compared with other industrial rocks and minerals, such factors as deposit size, amount of overburden, distance to the market, transportation, availability of labor, and accessibility to power and other utilities must be carefully considered. Few building stone deposits can justify the building of special roads, rail lines, or utility lines for the quarry operation (Power, 1975, p. 173).

Quartzite

Quartzite on the reservation is a possible source of silica raw material. Silica is the chief constituent in the manufacture of glass. It is also used as a metallurgical flux, as hydrafac sands, abrasives, molding sands, in ferroalloys, in ceramics and refractories; and in lesser amounts as a paint extender, mineral filler, insulation and in fertilizers and insecticides. Silica is the source of metallic silicon used in semiconductors of electronic instruments. It is used for the manufacture of silicones. (Carter and Savage, 1964, p. 174).

Quartzite from the lower part of the Precambrian Caddy Canyon Quartzite was quarried southwest of Pocatello for use as a flux in the electrometallurgical extraction of elemental phosphorus at the FMC Corp. plant (Trimble, 1976, p. 77). This quarry (now inactive) is located in the SW¼ sec. 6, T. 7 S., R. 34 E., and was operated by Wells Cargo, Inc.

Extensive quartzite beds crop out on and near the reservation. The Camelback Mountain Quartzite (Trimble, 1976, p. 24-26) is a medium-grained, siliceous, thick-bedded, massive orthoquartzite that weathers white, tan, brown, and brownish-gray. It is mostly white at the base. As previously mentioned, this rock is quarried near Inkom.

The Swan Peak Quartzite is, with the exception of a thin basal zone, a massive to thick-bedded white to yellowish-tan quartzite. The quartz grains are medium sized and well-sorted (Trimble and Carr, 1976, p. 18-19). The Swan Peak Quartzite forms conspicuous cliffs and rugged topography. It underlies the summit of North Putnam Mountain, and the hills north of Ross Fork Creek in T. 4 and 5 S., R. 36 E. It also crops out west of Bannock Peak in T. 9 S., R. 32 E., in Rattlesnake Canyon, T. 8 S., R. 33 E., and in sec. 20, T. 5 S., R. 38 E. (Mansfield, 1920, p. 33).

Other Precambrian and Paleozoic rocks on and near the reservation have quartzite units which may be potential silica sources. The Brigham Quartzite [now subdivided into the Papoose Creek Formation, Caddy Canyon Quartzite, Inkom Formation, Mutual Formation, Camelback Mountain Formation, and the Gibson Jack Formation (Trimble, 1976, p. 10)], the upper and lower portions of the Nugget Sandstone, and an upper member of the Wells Formation contain significant reserves of silica (Carter and Savage, 1964, p. 179).

Volcanic Ash, Pumice and Tuff

Volcanic ash (pumicite), pumice, and tuff are products of volcanic eruptions.

> Pumice and pumicite are produced by the violent expansion of dissolved gases in a viscous silicic lava such as rhyolite or dacite. Pumice is a light-colored, cellular, almost frothy rock made up of glass-walled bubble casts. It may occur as coherent, massive blocks, composed of highly vesicular glassy lava in either a flow or vent filling, or it may be more or less fragmented by violent eruption. Pumicite has the same origin, chemical composition and glassy structure as pumice, differing only in particle size. Particles less than 4 mm in diameter are designated pumicite. Pumice is usually found relatively close to the vent from which it was erupted, while pumicite may be carried by winds for great distances before settling as an accumulation of fine-grained ash or tuffaceous sediment. (Peterson and Mason, 1975, p. 991).

A partial consolidation of the volcanic ash (pumicite) through compaction or volcanic heat results in a rock described as a tuff or a welded tuff, respectively.

Mansfield (1920, p. 73) reported the occurrence of a buff, fine-grained tuff in the NE¼SW¼ sec. 20 T. 4 S., R. 36 E. (Figure 7). A small pit had been dug in search of building material. However, Mansfield judged this tuff to be too soft for this purpose.

Extensive beds of white volcanic ash were reported by Mansfield (1920, p. 77) in secs. 10 and 11, T. 3 S., R. 37 E. The ash consists largely of glass fragments with some feldspar. The fragments have a maximum diameter of 0.1 mm. Mansfield saw no potential for this material, except possibly in scouring preparations.

Other ash localities reported by Mansfield (1920, p. 117) include parts of Tps 7, 8, and 9 S., R. 32 E.; Tps 6, 7, 8, and 9 S., R. 33 E.; T. 4 and 5 S., R. 35 E.; T. 3 and 4 S., R. 36 E. He observed white volcanic ash beds 30 to 50 feet thick in some of the Tertiary formations. Microscopic examination of samples of better grade material showed it consists largely of tiny fragments of volcanic glass and some glassy feldspar. The ash is consolidated into friable beds.

Trimble and Carr (1976, p. 97) believe that the tuffaceous and pumiceous parts of the Walcott tuff and the Starlight Formation might possibly be suitable for abrasives, or lightweight concrete aggregates. The lower member contains very pure silicic tuff. The lower part of the Walcott tuff is fairly pure silicic ash.

The Starlight Formation (Carr and Trimble, 1963, p. G7) is named for its exposures along Starlight Creek about 10 miles southeast of American Falls in the Arbon Quadrangle. It is subdivided into a lower and upper member, separated by a vitric-crystal tuff. The upper member is mainly bedded rhyolitic tuff. The lower contains much rhyolitic tuff with numerous basalt flows and beds of marl. Some tuff beds are very loosely consolidated and more properly classified as ash.

Adjacent to the margin of the Snake River Plain, the Starlight Formation is mainly composed of bedded rhyolitic tuff, but is divided into an upper and a lower member by an intervening ash flow tuff known as the tuff of Arbon Valley. Locally, the lower member contains much basaltic tuff, breccia, and flows (Trimble, 1976, p. 36).

Asher (1965, p. 87) reports a significant amount of ash in the SW¼ sec. 34, T. 7 S., R. 36 E., 2 miles south of Inkom in a pit operated by the Idaho Portland Cement Co. The tuff is hard, fairly indurated, breaks into angular blocks, and cleaves into thin plates. It is bedded, strikes north, and dips 25º east. The deposit is 200 feet thick where exposed. The pumicite mined at this locality has been used by the Idaho Portland Cement Co. at Inkom in the production of a Portland pozzolan cement.

Chemical analysis of tuff and clay from the pit gave the following results (Asher, 1965, p. 88):

Fe_2O_3	0.7 percent
$A1_2O_3$	14.4
SiO_2	59.6
CaO	1.5
MgO	1.0
Total Na_2O	4.7
Total K_2O	7.2
Available N_2O	0.10
Available K_2O	0.34
Loss on ignition	10.1
	99.2 percent

The low-bulk density, heat and sound insulating characteristics, and excellent abrasive properties of pumice and pumicite give these materials useful industrial applications.

Pumice and pumicite are used for polishing glass, metals, leather, stone, and wood. Minor uses are in filters, adsorbents, carriers for insecticides, catalyst carriers, fillers, and soil conditioners. Pumicite is used in sizeable quantities as a pozzolanic additive in monolithic concrete where it increases the workability, strength, and durability and reduces the heat of hydration. Some soaps and scouring powders also contain pumicite. The main uses of pumice are in road surfacing materials, railroad ballast, building block aggregate, lightweight structural concrete, and as plaster aggregate (Peterson and Mason, 1975, p. 991).

Crushed stone, gravel, expanded shale and clay, and diatomite can be substituted for pumice and pumicite in most of their uses. Therefore, a market can exist only when a combination of cost, ease of handling processing, and the quality of the finished product are favorable (Peterson and Mason, 1975, p. 994).

Diatomaceous Clay (Diatomite)

Diatomite is a siliceous sedimentary rock composed principally of the fossilized skeletal remains of diatoms, single-celled aquatic plants related to algae. Diatomite has been formed by the induration of diatomaceous ooze and consists mainly of diatomaceous silica, a form of opal formed in the cell walls of the living organism (Kadey, 1975, p. 605).

No pure diatomite has been reported from the reservation or nearby areas, but a diatomaceous clay layer occurs in the American Falls Lake Beds. This layer is described by Carr and Trimble (1963, p. C40) as follows:

> A clay bed averaging about 6 feet thick that underlies many square miles around the American Falls Reservoir is estimated to contain about 70 percent diatoms. In one sample tested, 55 percent of the material was clay size and 41 percent silt size, leaving only 4 percent of the sample coarser than 0.062 mm. Ultrasonically segregated slime from this sample was found by x-ray methods to contain montmorillonite as a major constituent, quartz as a minor constituent, and traces of mica, kaolinite, and calcite. This clay bed occurs in the American Falls lake beds.

The diatom structure, low bulk density, high absorptive capacity, high surface area, and relatively low abrasive quality make diatomite valuable as a filler and an extender in paint, paper, rubber, and plastics; as an anti-coking agent, thermal insulating material, a catalyst carrier, a chromatographic support, and a polish, abrasive, and pesticide extender (Kadey, 1975, p. 605).

In evaluating a diatomite deposit, the following criteria must be considered: (1) color - the whiter the color the more desirable it is as a filler, (2) low block density - indicates freedom from contaminants such as sand and clay, (3) low degree of consolidation - highly consolidated diatomite is hard to mill and generally has a degraded structure. (Kadey, 1975, p. 618).

Apparently no attempt has been made to develop the diatomaceous clay layer in the American Falls Lake Beds. Possible uses may be found for it. However, the high clay content and resultant increased bulk density and decreased filtering capabilities do not seem to favor its development as a resource.

Energy Resources

Warm Springs and Geothermal Energy Potential

The increasing demands for energy in the United States have stimulated the search by Federal, state, and private agencies for alternative sources to fossil fuels, hydroelectric power, and nuclear fuels. Within the past few years, considerable attention has been focused on converting natural heat from the earth into useful energy.

The United States Congress passed the Geothermal Steam Act of 1970 (Public Law 91-581) which provides for leasing, development, and utilization of geothermal resources found on Federal lands (Godwin, Haigler, Riou, White, Muffler, and Wayland, 1971, p. 10-18). The Idaho Geothermal Leasing Act of 1972 (sections 47-1601 to 1611, Idaho Code) makes similar provisions for geothermal resources found on State and school lands.

As provided in the Geothermal Steam Act, Federal, state, and private lands have been investigated by the U.S. Geological Survey and classified on the basis of their geothermal potential. To classify lands, the concept of a geothermal resources province (GRP) was established. A GRP is defined as "an area in which higher than normal temperatures are likely to occur with depth, and in which there is a reasonable possibility of finding reservoir rocks that will yield steam or heated fluids to wells" (Godwin and others, 1971, p. 1).

Certain criteria are necessary if lands are to retain geothermal resources province classification status (Godwin and others, 1971, p. 7-8).

1) Volcanism of late Tertiary or Quaternary age--especially caldera structures, cones, and volcanic vents.

2) Geysers, fumaroles, mud volcanoes, or thermal springs at least 40º F. higher than average ambient temperature.

3) Subsurface geothermal gradients generally in excess of two times normal, as reflected in deep water wells, oil well tests, and other test holes.

Certain smaller areas with a geothermal resource province have been designated as known geothermal resource areas (KGRA's). According to Godwin and others (1971, p. 8), land is classified as a KGRA "when the prospects for extraction of geothermal steam or associated geothermal resources from an area are good enough to warrant expenditures of money for that purpose."

> The extent of a KGRA is influenced by such geologic factors as a pattern of temperature gradient, structure, stratigraphy, porosity, conductivity, permeability, heat source, and rate of recharge of fluids. The determination of a KGRA is made after evaluating the net effect of all geologic, geochemical, and geophysical data and any evidence derived from nearby discoveries, competitive interest, and other indicia (Godwin and others, 1971, p. 8).

That part of the Fort Hall Indian Reservation near the Lincoln Valley Warm Springs (Figure 7) has been designated as land potentially valuable for geothermal exploration (Young and Mitchell, 1973, p. 3).

There are many springs on and near the Fort Hall Indian Reservation. Most of these are, however, cold springs. The few known warm springs have low temperature, and are not a significant resource.

Mansfield (1952, p. 14) reports a warm spring near the southwest corner of sec. 18, T. 4 S., R. 38 E., south of the road, about one-half mile below and southeast of the Portneuf River-Lincoln Creek divide (Figure 7). It is small, has a constant flow, and a water temperature of 44º F. (7º C.).

Five springs comprise Yandell Springs in the SW¼SE¼ sec. 31, T. 3 S., R. 37 E., northwest of Yandell Mountain (Figure 7). Their temperatures range from 72 to 90º F. (22 to 32º C.), and they discharge more than 1,500 gpm, from a fault in Paleozoic limestone (Ross, 1971, p. 16). The chemical content of these waters is unreported.

The Lincoln Valley Warm Springs are in sec. 36, T. 3 S., 37 F. Five springs having temperatures ranging from 69 to 87º F. (21 to 31º C.), issue from fissures in limestone (Waring, 1965, p. 30).

Ross (1971, p. 16, 63) describes a thermal well which is just outside the reservation, about 5 miles north of Pocatello, in the SW¼ sec. 26, T. 5 S., R. 34 E. (Figure 7). It has been drilled to a depth of 581 feet in Pleistocene and Pliocene sediments. The waters have a temperature of 106º F. (41º C.), and a discharge of 200 gallons per minute. Chemical analysis and estimated aquifer temperature of the water are given in Table 3 and Table 4.

Indian Springs is about 7 miles west of the reservation in the SE¼ sec. 18, T. 8 S., R. 31 E. The water has a temperature of about 90º F. (32º C.), and issues from a fault in Paleozoic limestone. Two springs yielding just under 1,000 gpm each, supply water for a public swimming pool and for irrigation. One-half mile to the east, a well yields water with a temperature of 81º F. (27º C.). Another well, a few hundred yards from the spring, but on the west side of the fault discharges nonthermal water (Ross, 1971, p. 20-21).

Meinzer (1924, p. 295-303) believes that most of the thermal water in the southern Idaho-northern Utah and Nevada region is related to normal faults. He further concludes that although a large number of springs are in regions containing Cenozoic rocks, many are not closely related to such rocks, and do not derive their heat directly from them. Instead, he believes that the water is heated at depth by underlying magmas.

The Fort Hall Tribal Council has recently permitted a private company to explore the reservation for its geothermal potential (Francis Siler, 1977, personal commun.). However, the study is not yet complete, and data are unavailable.

TABLE 3
Chemical Analyses of Selected Thermal Springs and Wells near the
Fort Hall Indian Reservation, Idaho
(Young and Mitchell, 1973, p. 23, 27)

	Thermal Well (shown on Figure 2)	Indian Springs
Depth	581 feet	--
Discharge	15 gpm	1,540 gpm
Temp (°C)	40.5°	30°
Silica (Si)	20 mg/l	20 mg/l
Calcium (Ca)	70 mg/l	76 mg/l
Magnesium (Mg)	25 mg/l	19 mg/l
Sodium (Na)	150 mg/l	110 mg/l
Potassium (K)	21 mg/l	10 mg/l
Bicarbonate ($HC0_3$)	478 mg/l	254 mg/l
Carbonate ($C0_3$)	0 mg/l	0 mg/l
Sulfate ($S0_4$)	95 mg/l	19 mg/l
Phosphate (P)	0 mg/l	0.02 mg/l
Chloride (Cl)	87 mg/l	220 mg/l
Fluoride (F)	3.2 mg/l	0.7 mg/l
Nitrate ($N0_3$)	0.02 mg/l	0.13 mg/l
Dissolved solids (calculated)	706 mg/l	600 mg/l
Dissolved solids (tons per acre-foot)	0.96	0.82
Hardness:		
$CaC0_3$	280 ppm	270 ppm
Non-carbonate	0 ppm	60 ppm
Specific Conductance	1,170 micromhos at 25°C	1.100 micromhos at 25°C
pH (field)	7.7	7.5
Percent sodium	52	46
Sodium absorption ratio	3.9	2.9

gpm = gallons per minute Micromhos = $l/ohms^6$
mg/l = milligrams per liter ppm = parts per million

TABLE 4
Estimated Aquifer Temperatures and Atomic Ratios of Selected Thermal Springs and Wells near the Fort Hall Indian Reservation.
(Young and Mitchell, 1973, p. 29, 34)

	Thermal Well (shown on Figure 2)	Indian Springs
Aquifer temp. from Geochemical Thermometers (rounded to 5°C)		
Silica	65°C	65°C
Na-K-Ca	185°C	70°C
Atomic ratios		
Sodium/Potassium	12.1	18.7
Calcium/Bicarbonate	0.223	0.456
Magnesium/Calcium	0.589	0.412
Sodium/Calcium	3.74	2.52
Chloride/Bicarbonate plus Carbonate	0.313	1.49
Chloride/Fouoride	14.6	168.0
/Calcium/Sodium	0.203	0.288

Oil and Gas

Commercial quantities of oil or natural gas have not been produced in Idaho. Exploratory wells have been dry, but no deep drilling has been done.

Kirkham (1922, p. 2) concluded that the southeastern part of Idaho has pmr potential for oil and natural gas. The fact that commercial oil and gas production occurs from rock formations of similar age in adjacent states has generated optimism over the years.

Savage (1964b, p. 151) believed that about 12,000 feet of the 23,000 feet of exposed sedimentary rock in southern and southeastern Idaho have characteristics which might make them good reservoir rocks for oil and gas. He reported that when broken many of the exposed strata have an oil-like odor, and that oily substances in some of the rocks will burn. No significant oil seeps have been found in the area.

However, Piper (1924) investigated the petroleum potential in Power and Oneida Counties, and concluded that the Carboniferous rocks in these counties do not contain any strata that would serve as ideal reservoir rocks. Many of the sandstones and limestones have been silicified and dolomitized, respectively, and no favorable stratigraphic traps have been found (Piper, 1924, p. 19-21).

No record was found of any exploratory wells on or near the reservation.

Coal

Mansfield (1920, p. 114) reported two coal prospects in the Arbon Valley area. One, in the NW¼NW¼ sec. 23, T. 7 S., R. 33 E. (Figure 7) was in carbonaceous, plant-bearing shales. The other explored an obsidian dike. Neither prospect found coal and there are no other references to coal occurring on the reservation.

The coal occurrence nearest to the reservation is the Fall Creek area, about 50 miles northeast of Fort Hall. The deposit consists of a sheared shale in which there are thin lenses of coal, clay, and limestone. The ash content of the material is too high for commercial use (Kiilsgaard, 1964, p. 63).

Peat

Peat is an unconsolidated deposit of semi-carbonized vegetable tissue formed by partial decomposition of various plants in a water saturated environment, such as a bog or marsh. It represents the primary stage of the conversion of vegetable matter to coal. Peat contains varying amounts of carbon, hydrogen, oxygen, and nitrogen in a ratio of about 90 percent water to 10 percent organic material. Structures of the organic matter can usually be seen. Peat burns readily when dry.

Peat in southeastern Idaho occurs in relatively small deposits of reed sedge and humus peat adjacent to swampy river flats. Commercial peat production has come from bogs on Marsh Creek near Downy in Bannock County, and from similar deposits along the Teton River near Driggs and Victor in Teton County. Total production is unknown (Savage and LaHeist, 1964, p. 144-145).

Peat occurs north of Pocatello along Ross Fork Creek southeast and southwest of the Fort Hall Agency (Savage and LaHeist, 1964, p. 146).

In 1976 virtually all peat sold in the United States was used for agricultural and horticultural purposes, with 81 percent being used for general soil improvement (Commodity Data Summaries, 1977, p. 118). The remainder was used principally in potting soils, for packing flowers and shrubs, and in mixed fertilizers. Major markets are in the North Central, Northeast, and Middle Atlantic States.

Potential Resources

Fluorite

Although fluorite deposits have not been found on the Fort Hall Indian Reservation, there are some geologic features that suggest fluorite deposits might be present. The common phosphate mineral in the phosphorite is carbonate fluorapatite, which contains fluorine. Average fluorine content of the Phosphoria Formation is 3.1 percent (Gulbrandsen). Van Alstine (1976) suggests that fluorite deposits are found adjacent to rift zones or lineaments and he projects such a structure through southeast Idaho. Shawe (1976) indicated on a regional map that igneous rocks in southeast Idaho contain anomalously high percentages of fluorine. Trimble and Carr (1976a, table 9) report that silicic tuffs in and near the Fort Hall Indian Reservation contain as much as 0.22 percent fluorine. Barite, commonly found with fluorspar deposits, occurs in the SE¼NE¼ sec. 10, T. 8 S., R. 31 E., about 2½ miles west of the reservation.

There are abundant silicic volcanic rocks, in part associated with the Snake River Valley rift, and these might be favorable rocks in which to search for minable deposits of fluorite. Another area that should be searched for fluorite is in the brecciated and dolomitized rock adjacent to the Deep Creek Mountain thrust fault near the southwest corner of the reservation.

Phosphate

The phosphate rock in the Meade Peak Phosphatic Member of the Phosphoria Formation has been well delineated by the current mining operation in the northeastern part of the reservation. The known reserves in this area are not published.

Trimble and Carr (1976n, p. 28) report that the Manning Canyon Shale in the southwestern part of the reservation contains thin phosphatic beds with as much as 30 percent P_2O_5. Whether or not these beds will ever become a minable resource will of course depend on whether there is sufficient tonnage available to encourage mining. The larger and more easily obtainable phosphate rock in the northeast part of the reservation will remain the most important source of phosphate on the reservation for many years.

Uranium and Vanadium

Both of these elements are present in more than trace amounts in the phosphate rock and could constitute a resource.

ENVIRONMENTAL AND SOCIAL EFFECTS

The only mining operation on the reservation at this time is J. R. Simplot Co.'s Gay mine. There are several active and intermittently active sand and gravel quarries. However they are relatively insignificant with respect to land disturbance, noise, and dust pollution. The area's only other major operations are the quarrying operations being carried out in conjunction with the cement plant at Inkom.

Although phosphate mining at the Gay mine results in local surface disturbances, the mined out areas are backfilled, graded, contoured, and replanted as mining proceeds. Overburden and waste from the newly opened pit areas are used to fill the mined areas.

Development of limestone, building stone, quartzite, or volcanic ash quarries would result in only local noise and dust pollution. These operations would probably be small, and away from population centers.

Preference is given to Indians in employment at the Gay mine, and between 60 and 75 percent of the work force consists of tribal members (Francis Siler, 1977, personal commun.). This may represent between 9 and 12 percent of the total labor force available on the reservation. The mine provides a significant boost to the local economy.

RECOMMENDATIONS FOR FURTHER WORK

The stratigraphy, structural controls, and general geology of the phosphate areas are well known. Thus, any further study probably could not contribute significantly to ore reserves.

However, the Fort Hall tribes should endeavor to retain, or have available for their use, all drill core data, including core logs from the unmined, submarginal areas, geologic maps, and any other geologic data that has been collected during the life of the mine, or from other exploration projects on the reservation.

Areas where relatively pure limestone, quartzite, pumicite, tuff, and peat occur should be sampled to determine the economic potential.

The part of the reservation underlain by the Nugget Sandstone should be carefully examined and the building stone potential of the more favorable zones estimated.

Fluorite deposits should be searched for in areas underlain by silicic tuffs and in brecciated and dolomitized rock west of Bannock Peak.

Although the metallic mineral potential is considered low, a reconnaissance geochemical sampling program might be worthwhile. Particular attention should be directed to the areas underlain by the Scout Mountain Member of the Pocatello Formation and the zone of brecciated and dolomitized rock in the southwestern part of the reservation.

The potential for geothermal energy appears low. The Fort Hall tribes(Shoshone and Bannock) appear to have already taken the initiative in investigating the area's geothermal potential.

REFERENCES

Altschuler, Z. S., Berman, Sol, and Cuttita, Frank, 1967, Rare earths in phosphorite-geochemistry and potential recovery, in Anatomy of the western phosphate field--Intermountain Assoc. Geologists 15 Ann. Field Conf.: Salt Lake City, Utah, Intermountain Assoc. Geologists, p. 125-135.

Altschuler, Z. S., Clarke, R. S., Jr., and Young, E. J., 1958, Geochemistry of uranium in apatite and phosphorite: U.S. Geol. Survey Prof. Paper 314-D, 90 p.

Anderson, A. L., 1928, Portland cement materials near Pocatello, Idaho: Idaho Bur. Mines and Geol. Pamph. 29, 15 p.

Armstrong, F. C., and Cressman, E. R., 1963, The Bannock thrust zone southeastern Idaho: U.S. Geol. Survey Prof. Paper 374-J, 22 p.

Asher, R. R., 1965, Volcanic construction materials in Idaho: Idaho Bur. Mines and Geol. Pamph. 135, 150 p.

Bell, R. N., 1904, Sixth annual report of the mining industry of Idaho for the year 1904: Annual report of the State Mine Inspector, 139 p.

______,1905, Seventh annual report of the mining industry of Idaho for the year 1905: Annual report of the State Mine Inspector, 149 p.

Caldwell, Harry H., ed., 1970, Idaho economic atlas: Idaho Bur. Mines and Geol., Moscow, Idaho, 82 p.

Campbell, Stewart, 1922, Twenty-fourth annual report of the mining industry of Idaho for the year 1922- Annual report of the State Mine Inspector, 209 p.

Carr, W. J., and Trimble, D. E., 1961, Upper Paleozoic rocks in the Deep Creek Mountains, Idaho, in Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424-C, p. C181-C184.

_____,1963, Geology of the American Falls quadrangle, Idaho: U.S. Geol. Survey Bull. 1121-G, 44 p.

Commodity Data Summaries, 1977, U.S. Bureau of Mines, 199 p.

Cook, E. F., 1957, Radioactive minerals in Idaho: Idaho Bur. Mines and Geol. Mineral Resource Rept. 8, 5 p.

Cooksley, J. W., Jr., 1967, Application of geophysical methods in phosphate exploration, southeastern Idaho, in Anatomy of the western phosphate field-Intermountain Assoc. Geologists 15th Ann. Field Conf.: Salt Lake City, Utah, Intermountain Assoc. Geologists, p. 161-166.

Crittenden, M. D., Jr., Schaeffer, F. E., Trimble, D. E., and Woodward, L. A., 1971, Nomenclature and correlation of some upper Precambrian and basal Cambrian sequences in western Utah and southeastern Idaho: Geol. Soc. America Bull., v. 82, no. 3, p. 581-602.

Day, R. L., 1973, Trends in the phosphate industry of Idaho and the Western Phosphate Field: Idaho Bur. Mines and Geol. Pamph. 155, 63 p.

Emigh, G. D., 1975, Phosphate rock in Lefond, S. J., ed., Industrial Minerals and Rocks, 4th ed., AIME, p. 935-962.

Fenneman, N. M., 1931, Physiography of the western United States: New York and London, McGraw Hill Book Company, Inc., 534 p.

Finch, W. I., 1977, Uranium, in Geotimes, v. 22, no. 1, p. 43.

Fowler, H. B., 1949, Phosphate mining by the Simplot Fertilizer Company near Fort Hall, Idaho: Am. Inst. Mining Engineers Trans., v. 184, p. 291-295.

Godwin, L. H., Haigler, L. B., Rioux, R. L., White, D. E., Muffler, L. J. P., and Wayland, R. G., 1971, Classification of public lands valuable for geothermal steam and associated geothermal resources: U.S. Geol. Survey Circ. 647, 18 p.

Gulbrandsen, R. A., 1967, Some compositional features of phosphorites of the Phosphoria Formation, in Anatomy of the western phosphate field--Intermountain Assoc. Geologists 15th Ann. Field Conf.: Salt Lake City, Utah, Intermountain Assoc. of Geologists, p. 99-102.

Hale, L. A., 1967, Phosphate exploration using gamma-radiation logs, Dry Valley, Idaho, in Anatomy of the western phosphate field--Intermountain Assoc. Geologists 15th Ann. Field Conf.: Salt Lake City, Utah, Intermountain Assoc. Geologists, p. 147-159.

Harris, R. A., Davidson, D. F., Arnold, B. P., 1954, Bibliography of the geology of the western phosphate field: U.S. Geol. Survey Bull. 1018, 89 p.

Hill, J. M., 1916, Notes on the fine gold of Snake River, Idaho: U.S. Geol. Survey Bull. 620-L, p. 271-294.

Hubbard, H. A., and Erickson, G. E., 1973, Limestone and dolomite, in Brobst, D. A., and Pratt, W. P., ed., United States mineral resources: U.S. Geol. Survey Prof. Paper 820, p. 357-364.

Idaho State Mine Inspector, Annual reports of the mining industry of Idaho for the years 1902-1975.

Kadey, F. L., Jr., 1975, Diatomite, in Lefond, S. J., ed., Industrial Minerals and Rocks, 4th ed., AIME, p. 605-635.

Kiilsgaard, T. H., 1964, Coal, in Mineral and water resources of Idaho: Idaho Bur. Mines and Geol. Spec. Rept. no. 1, p. 58-66.

Kirkham, V. R. D., 1922, Petroleum possibilities of certain anticlines in southeastern Idaho: Idaho Bur. Mines and Geol. Bull. 4, 36 p.

______,1924, Geology and oil possibilities of Bingham, Bonneville, and Caribou Counties, Idaho: Idaho Bur. Mines and Geol. Bull. 8, 116 p.

Kummel, Bernhard, 1954, Triassic stratigraphy of southeastern Idaho and adjacent areas: U.S. Geol. Survey Prof. Paper 254-H, p. 165-194.

Love, J. D., 1967, Vanadium and associated elements in the Phosphoria Formation in the Afton area, western Wyoming, in Anatomy of the western phosphate field--Intermountain Assoc. Geologists 15th Ann. Field Conf.: Salt Lake City, Utah, Intermountain Assoc. Geologists, p. 113-118.

Mansfield, G. R., 1920, Geography, geology, and mineral resources of the Fort Hall Indian reservation, Idaho: U.S. Geol. Survey Bull. 713, 152 p.

_____,1927, Geography, geology, and mineral resources of part of southeastern Idaho: U.S. Geol. Survey Prof. Paper 152, 453 p.

_____,1929, Geography, geology, and mineral resources of the Portneuf Quadrangle, Idaho: U.S. Geol. Survey Bull. 803,110 p.

_____,1952, Geography, geology, and mineral resources of the Ammon and Paradise Valley quadrangles, Idaho: U.S. Geol. Survey Prof. Paper 238, 92 p.

Prater, L. S., 1948, Reaction rates in the acidulation of Idaho phosphate rock with sulfuric acid: Idaho Bur. Mines and Geol. Pamph. 79, 8 p.

Ross, Sylvia H., 1971, Geothermal potential of Idaho: Idaho Bur. Mines and Geol. Pamph. 150, 72 p.

Sando, W. J., Dutro, T. J., Jr., Sandberg, C. A., and Mamet, B. L., 1976, Revision of Mississippian stratigraphy, Eastern Idaho and Northeastern Utah: Jour. Research, U.S. Geol. Survey, v. 4, no. 4, July-August 1976, p. 467-479.

Savage, C. N., 1964a, Limestones and related materials, in Mineral and water resources of Idaho: Idaho Bur. Mines and Geol. Spec. Rept. no. 1, p. 111-116.

_____,1964b, Petroleum and natural gas, in Mineral and water resources of Idaho: Idaho Bur. Mines and Geol. Spec. Rept. no. 1, p. 145-152.

Savage, C. N., and LaHeist, B. A., 1964, Peat, in Mineral and water resources of Idaho: Idaho Bur. Mines and Geol. Spec. Rept. no. 1, p. 143-145.

Schmitt, W. O., 1967, The Gay mine, Fort Hall, Idaho, in Anatomy of the Western Phosphate Field: Intermountain Assoc. of Geologists, 15th annual field conference, 1967, p. 195-202.

Schwarze, D. M., 1967, History of the Conda operations Underground to strip mining, in Anatomy of the western phosphate field--Intermountain Assoc: Geologists 15th Ann. Field Conf.: Salt Lake City, Utah, Intermountain, Assoc. Geologists, p. 187-194.

Service, A. L., 1966, An evaluation of the Western phosphate industry and its resources (in five parts); Part 3, Idaho: U.S. Bur. Mines Rept. Inv. 6801, 201 p.

_____,1967, Evaluation of the phosphate reserves in southeastern Idaho, in Anatomy of the Western Phosphate Field: Intermountain Assoc. of Geologists, 15th annual field conference, 1967, p. 73-95.

_____,1967, History and development of the phosphate industry in southeastern Idaho, in Anatomy of the western phosphate field--Intermountain Assoc. Geologists 15th Ann. Field Conf.: Salt Lake City, Utah, Intermountain Assoc. Geologists, p. 176-184.

Service, A. L., and Popoff, C. C., 1964, An evaluation of the western phosphate industry and its resources (in five parts); Part 1, an introductory review: U.S. Bur. Mines Rl 6485, 86 p.

Shawe, D. R., 1976, Geology and resources of fluorine in the United States: U.S. Geol. Survey Prof. Paper 933, 99 p.

Shekarchi, E., 1976, Silicon, in Mineral facts and problems, 1975 ed.: U.S. Bur. Mines Bull. 667, p. 989-1000.

Shelton J. E., and Drake, H. J., 1976, Stone, in Mineral facts and problems, 1975 ed.: U.S. Bur. Mines Bull. 667, p. 1031-1048.

Staley, W. W., 1945, Coal in Idaho: Idaho Bur. Mines and Geol. Mineral Research Rept. 1, 4 p.

_____,1946, Gold in Idaho: Idaho Bur. Mines and Geol. Pamph. 68, 32 p.

_____,1950, Pumice and perlite in Idaho: Idaho Bur. Mines and Geol. Mineral Research Rept. 6, 10 p.

Stowasser, W. F., 1975, Phosphate rock, in Mineral facts and problems, 1975 ed.: U.S. Bur. Mines Bull. 667, p. 819-834.

Trimble, D. E., 1976, Geology of the Michaud and Pocatello quadrangles, Bannock and Power Counties, Idaho, U.S. Geol. Survey Bull. 1400, 88 p.

Trimble, D. E., and Carr, W. J., 1976, Geology of the Rockland and Arbon quadrangles, Power County, Idaho- U.S. Geol. Survey Bull 1399, 115 p.

U.S. Department of Commerce, 1974, Federal and State Indian reservations and Indian Trust Areas: U.S. Govt. Printing office, Washington, 604 p.

U.S. Department of the Interior, 1975, Critical water problems facing the eleven western states, U.S. Govt. Printing Office, Washington, p. 280-297.

U.S. Department of the Interior and U.S. Department of Agriculture, 1976, Development of phosphate resources in southeastern Idaho: Draft Environmental Impact Statement, v. l; prepared jointly by the U.S. Dept. of Interior (U.S. Geol. Survey and Bur. of Land Management) and the U.S. Dept. Agriculture (Forest Service), p. 2-1 - 1-537, 2-1 - 2-73.

Van Alstine, R. E., 1976, Continental rifts and lineaments associated with major fluorspar districts: Econ. Geol., v. 71, no. 6, p. 977-987.

Waring, G. A., 1965, Thermal springs of the United States and other countries of the world - a summary: U.S. Geol. Survey Prof. Paper 492, 383 p.

Weeks, F. B., and Heikes, V. C., 1908, Copper, Notes on the Fort Hall mining district, Idaho: U.S. Geol. Survey Bull. 340-B, p. 175-183.

West, S. W., and Kilburn, Chabot, 1963, Ground water for irrigation in part of the Fort Hall Indian Reservation, Idaho: U.S. Geol. Survey Water-Supply Paper 1576-D, 33 p.

Young, H. W., and Mitchell, J. C., 1973, Geothermal investigations in Idaho, Part I - Geochemistry and geologic setting of selected thermal waters: Idaho Dept. Water Adm., Water Inf. Bull. 30, 43 p.

Click back button (<<) on toolbar to return to text

Table 1.--Stratigraphic sequences on the Fort Hall Indian Reservation

Age	Northeastern Area (after Mansfield, 1920)	Southeastern Area (after Trimble and Carr, 1976a, b)
Quaternary	Alluvium, travertine, volcanic rocks and ash	Alluvium, travertine, volcanic rocks,
Tertiary	Salt Lake Formation Unconformity	Starlight Formation
Jurassic	Twin Creek Limestone Nugget Sandstone Wood Shale	Unconformity
Triassic(?)	Deadman Limestone Higham Grit Unconformity Timothy Sandstone	
Triassic	Portneuf Sandstone (Thaynes Group) Fort Hall Formation (Thaynes Group) Ross Fork Limestone Dinwoody Formation	
Permian	Phosphoria Formation Rex chert or cherty shale member Meade Peak Phosphatic member Park City Formation Grandeur member	
Pennsylvanian and Permian		Oquirrh Formaton
Pennsylvanian	Wells Formation	Wells Formation
Mississippian and Pennsylvanian		Manning Canyon Shale
Mississippian	Brazer Limestone Madison Limestone	Great Blue Limestone Deep Creek Formation Lodgepole Limestone
Devonian	Three Forks Limestone Jefferson Limestone	Beirdneau Formation Hyrum Dolomite
Silurian		Laketown Dolomite
Ordovician	Fish Haven Dolomite Swan Peak Quartzite Garden City Formation	Fish Haven Dolomite Swan Peak Quartzite Garden City Limestone
Cambrian	St. Charles Formation Worm Creek Quartzite Member Bloomington Formation Blacksmith Formation Brigham Quartzite	St. Charles Formation Worm Creek Quartzite Member Nounan Dolomite Bloomington Formation Elkhead Limestone Gibson Jack Formation
Cambrian and Precambrian		Camelback Mountain Quartzite
Precambrian		Mutual Formation Inkom Formation Caddy Canyon Quartzite Papoose Creek Formation

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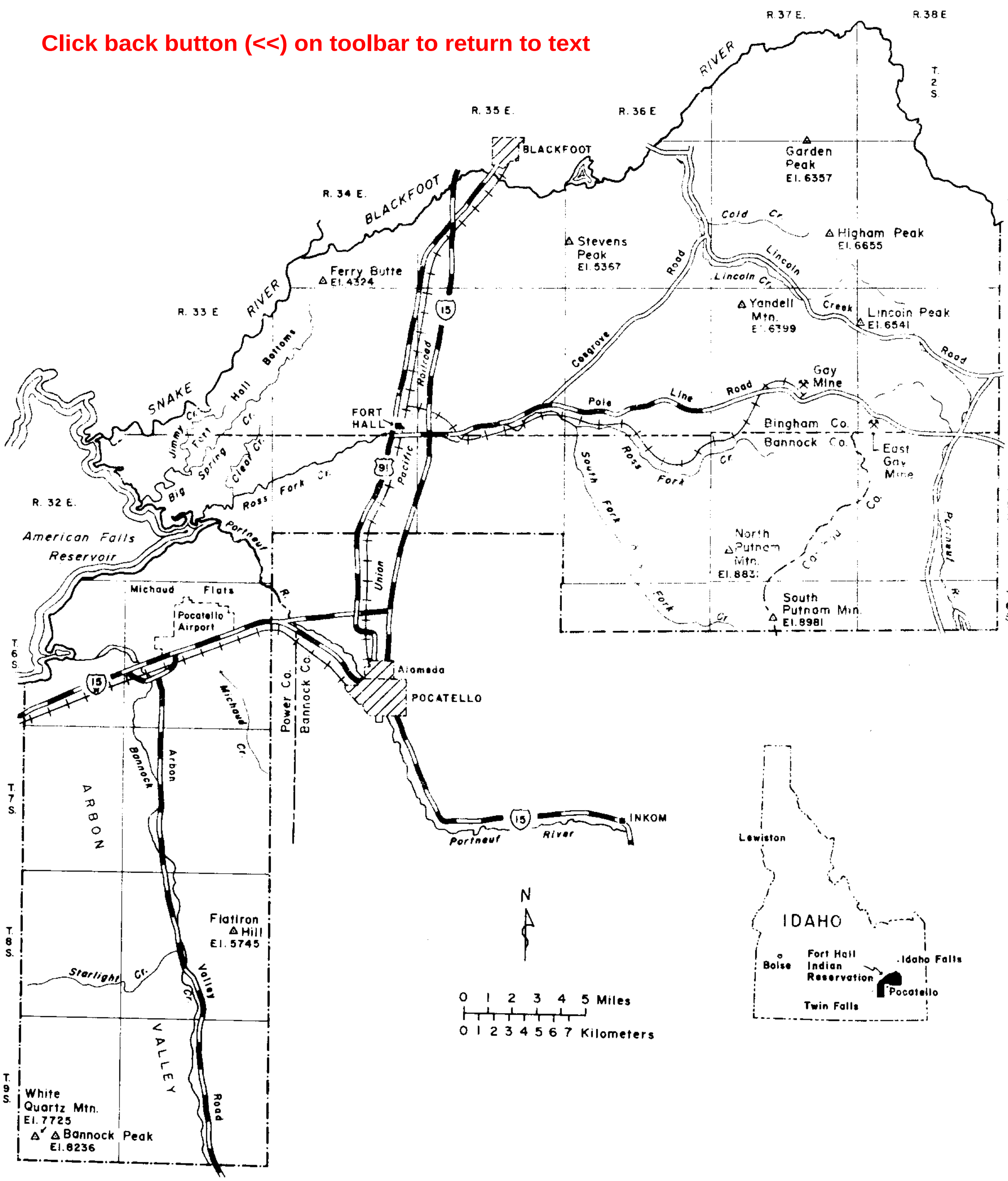

Figure 1. Index map of the Fort Hall Indian Reservation, Idaho.

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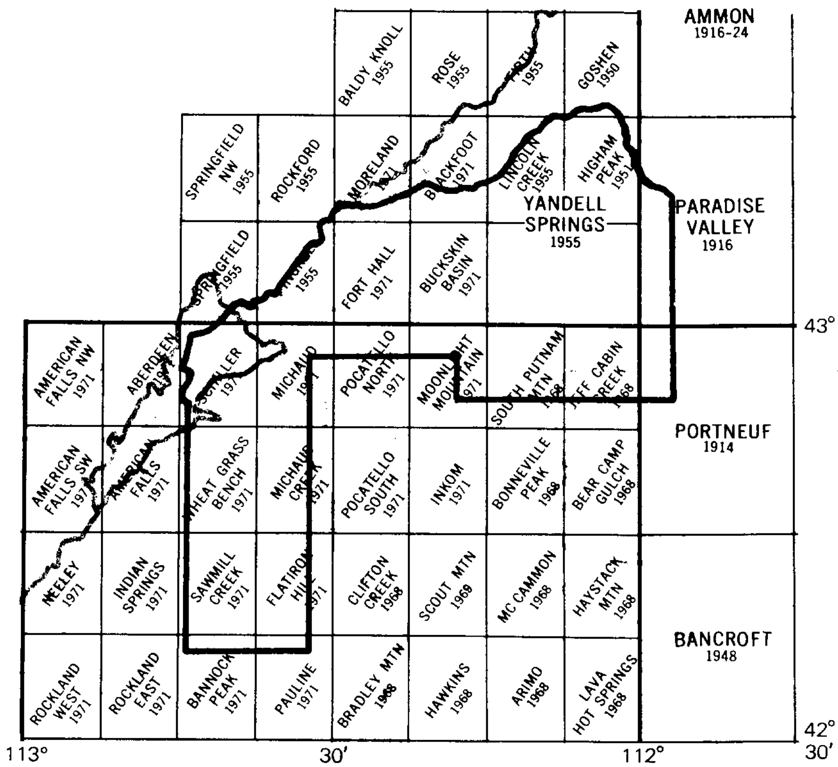

Figure 2. Index to topographic maps.

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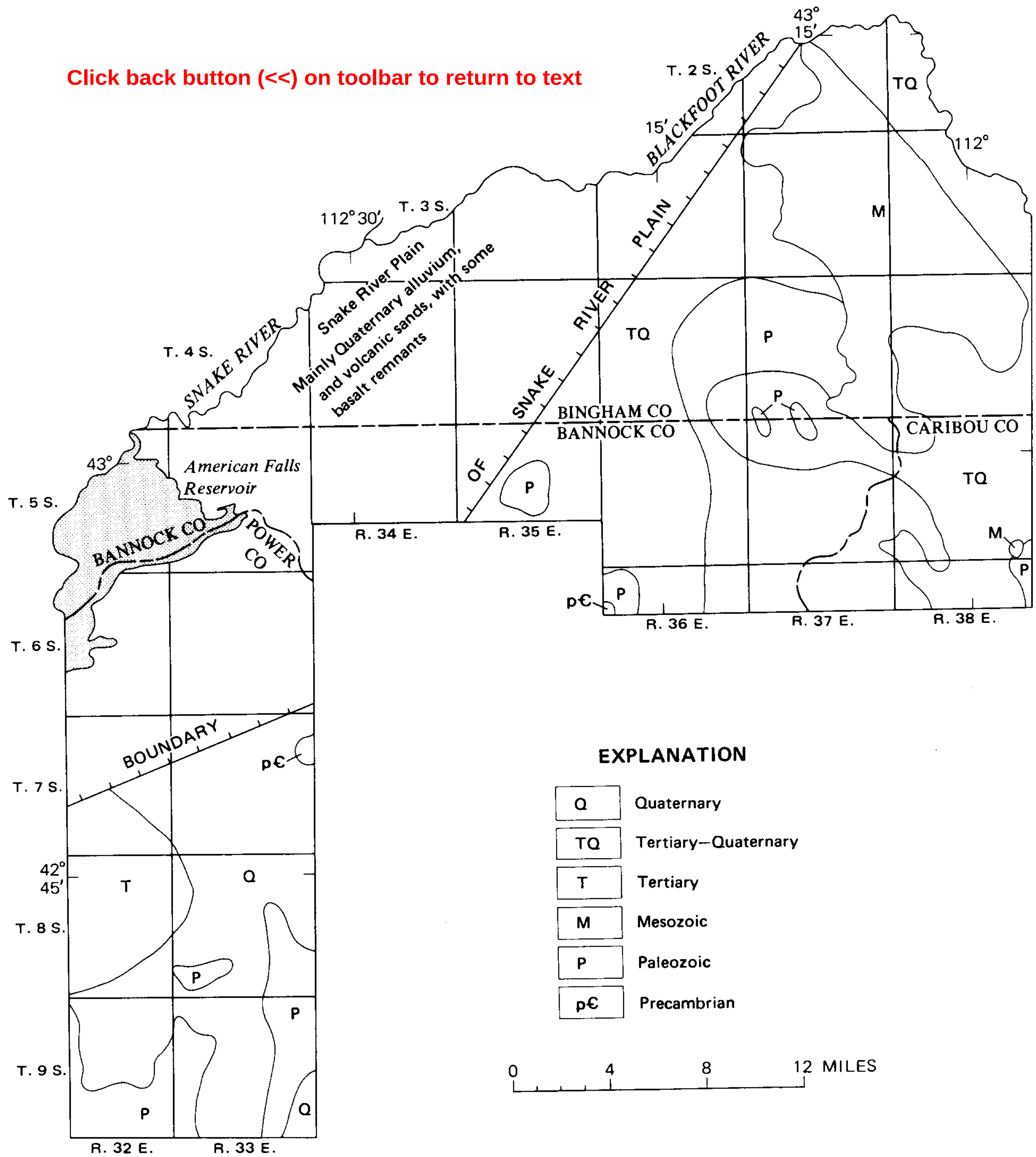

Figure 3. Map showing areas of outcropping rocks of various ages - Fort Hall Indian Reservation.

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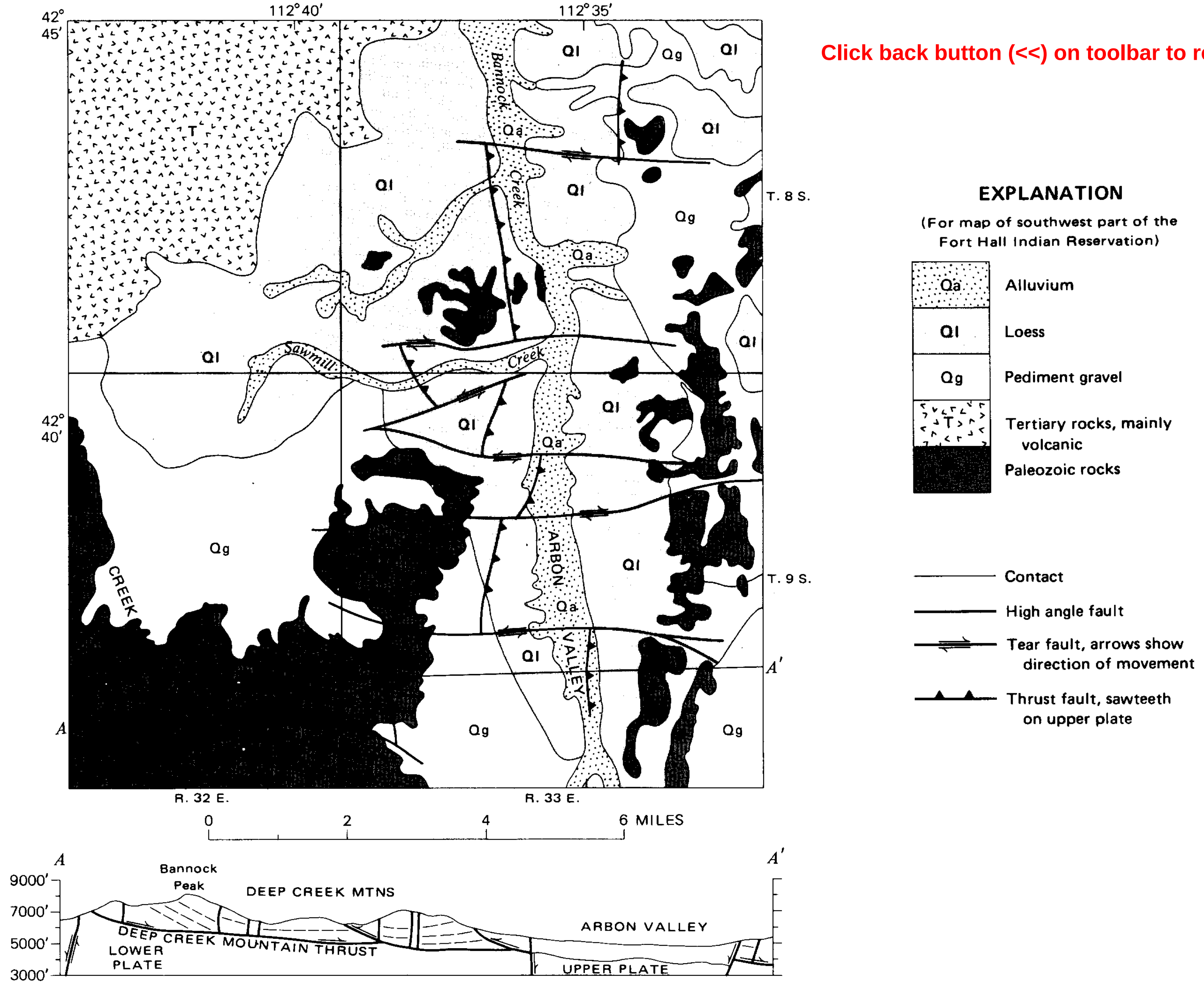

Figure 4. Generalized geologic map, southwestern part of Fort Hall Indian Reservation (adapted from Trimble and Carr, 1976a).

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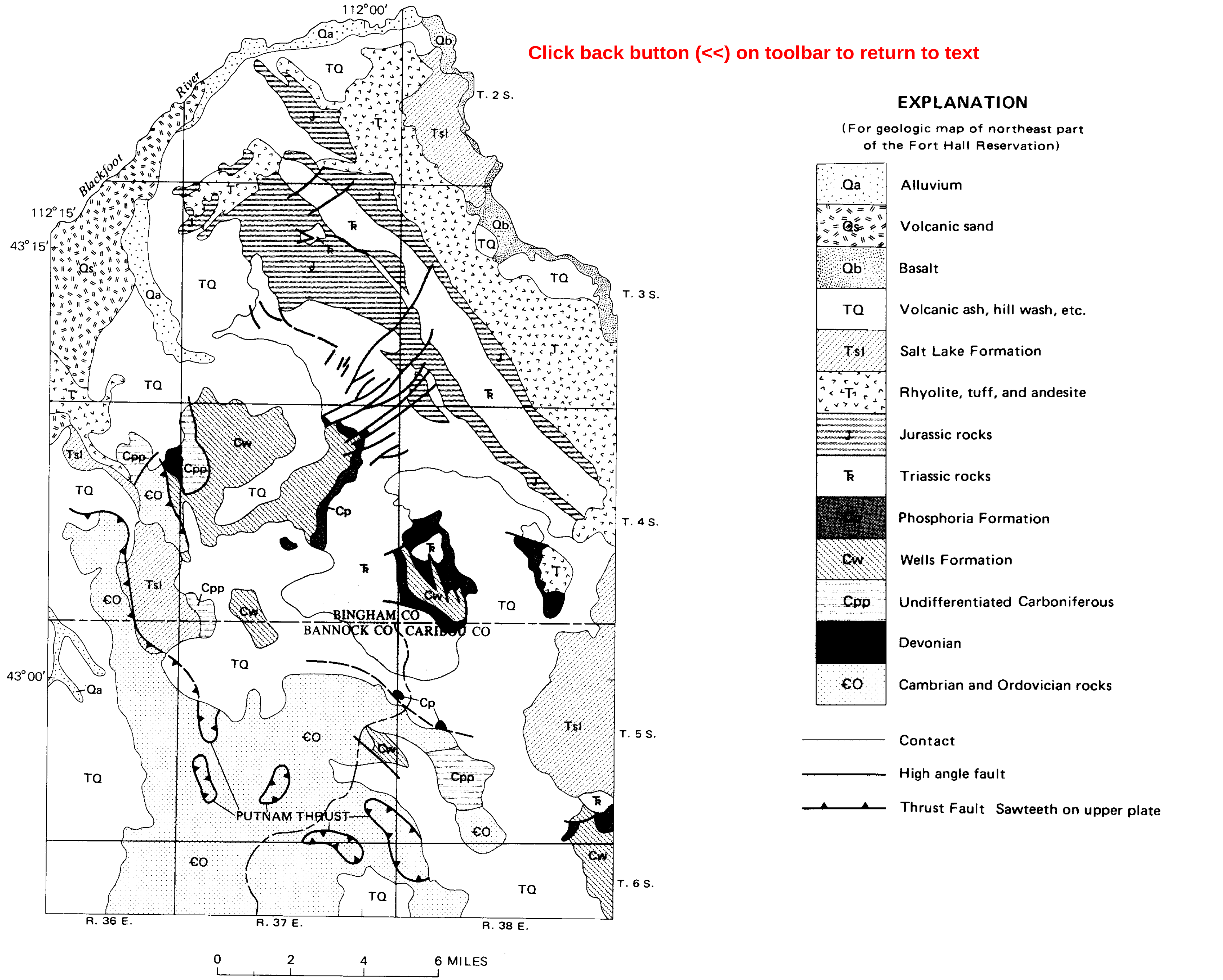

Figure 5. Generalized geologic map, northeastern part of Fort Hall Indian Reservation (adapted from Mansfield, 1920, pl. I).

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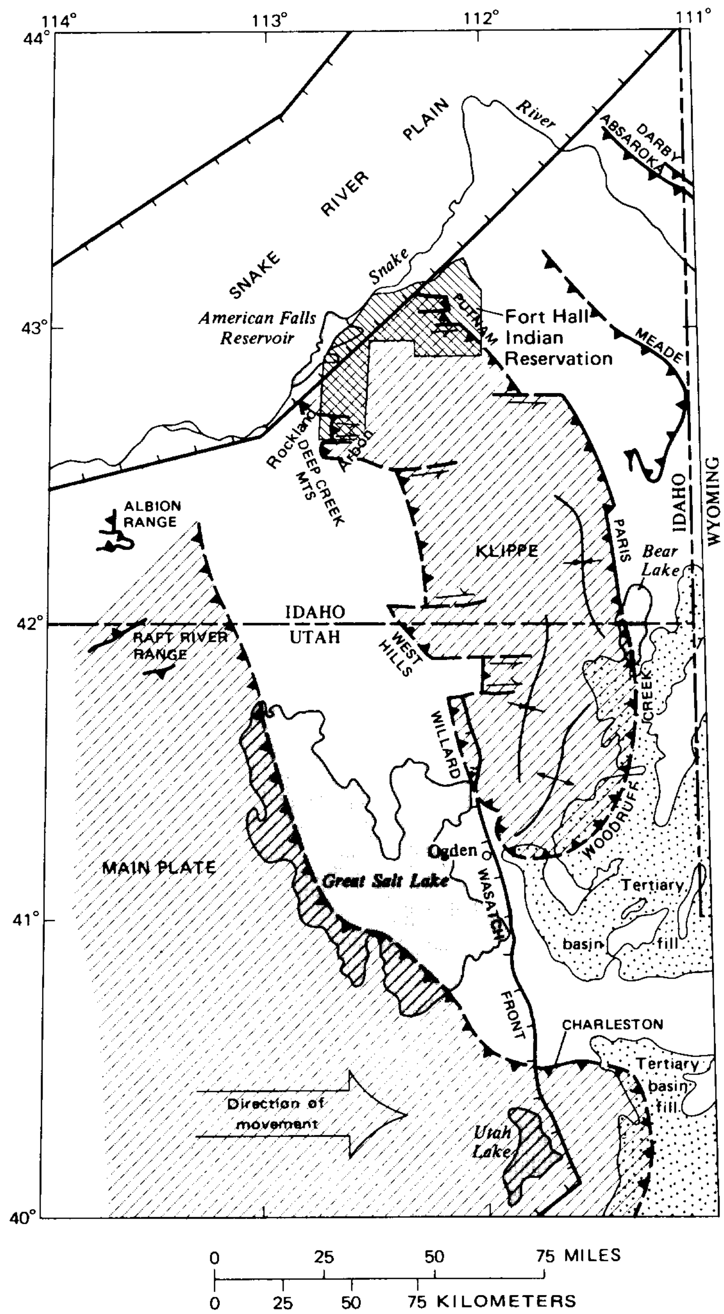

Figure 6. Map showing regional structural setting of Fort Hall Indian Reservation (from Trimble and Carr, 1976a, fig. 15).

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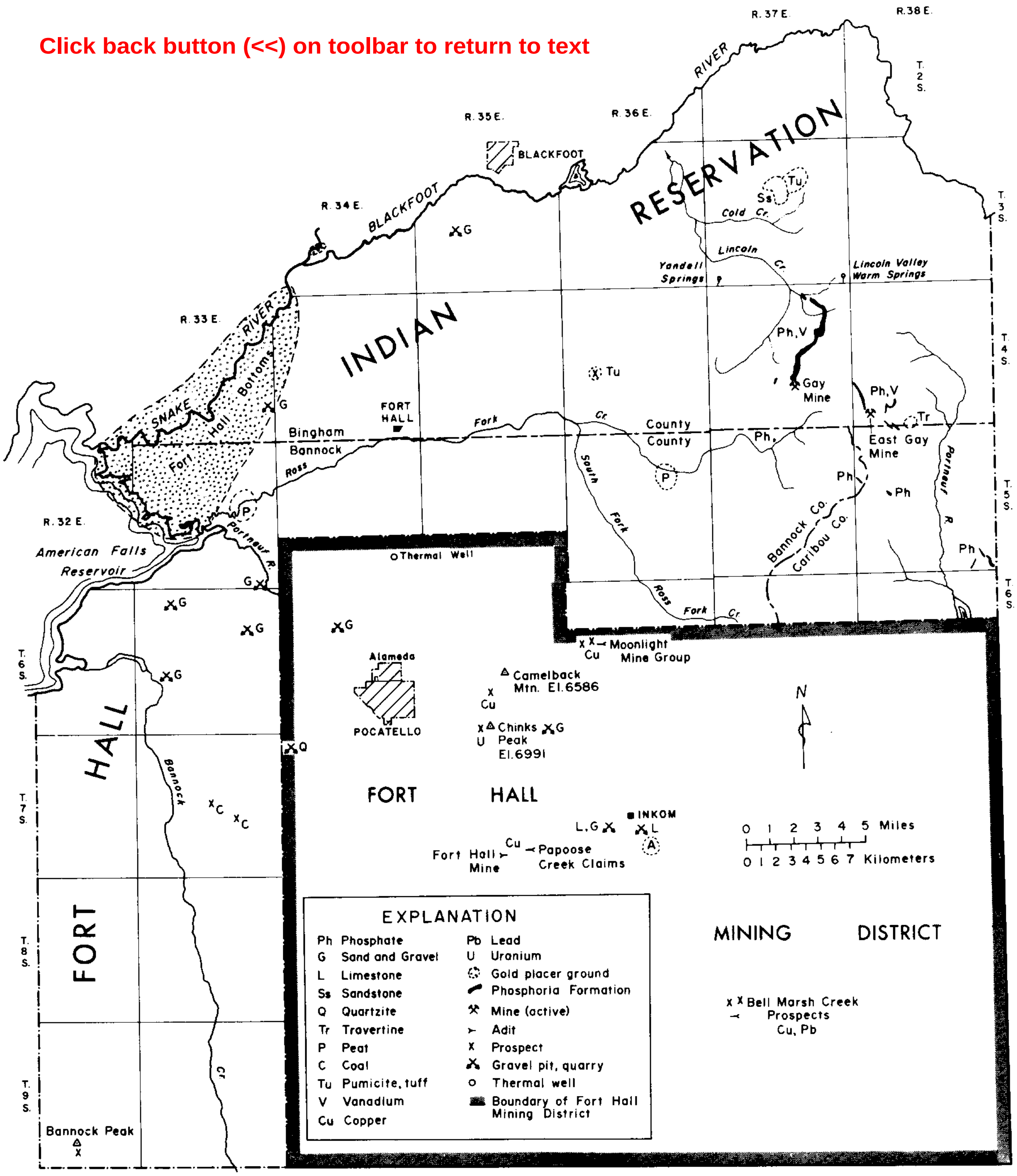

Figure 7. Mineral occurrences, gravel pits, and quarries on and near the Fort Hall Indian Reservation, Idaho.

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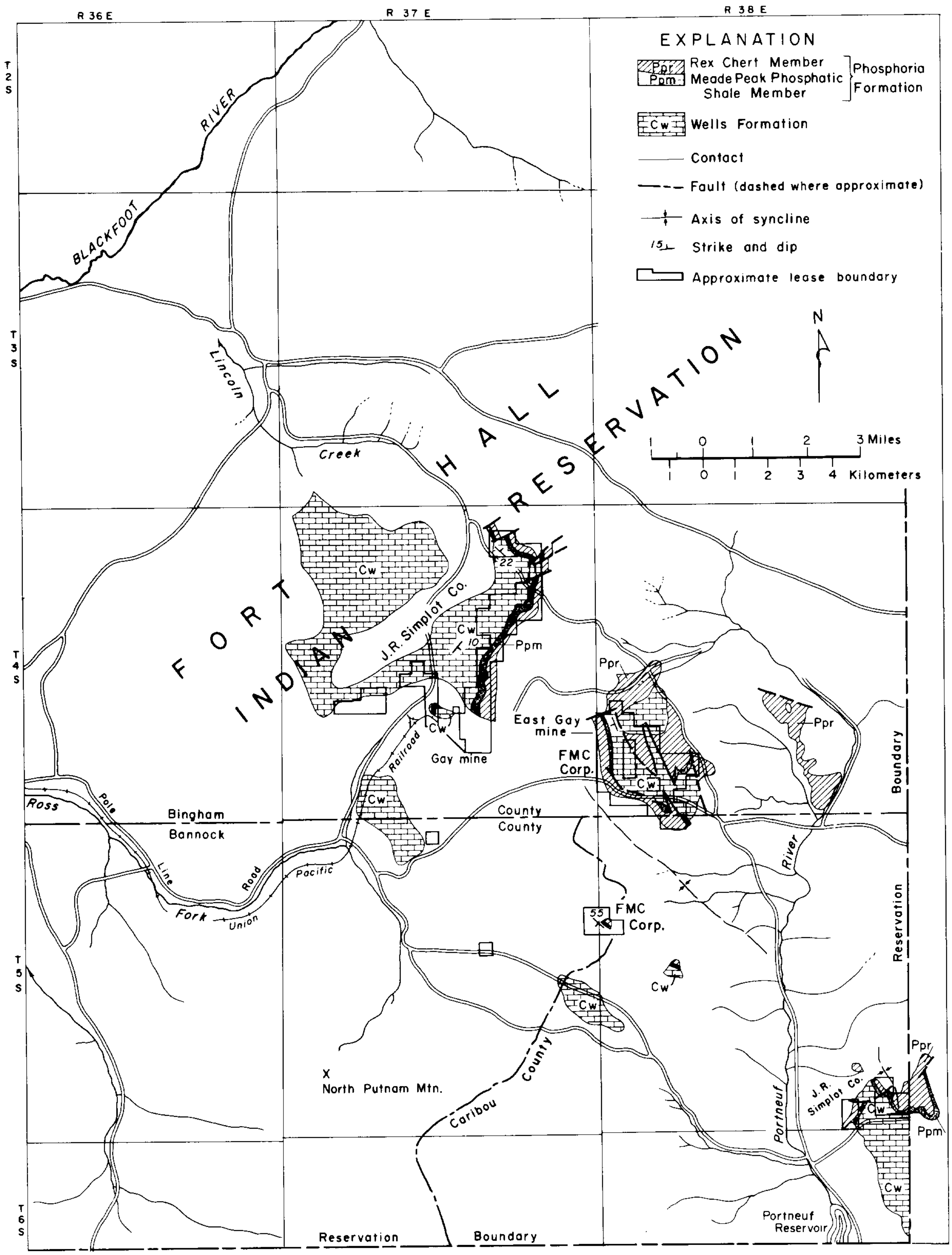

Figure 8. Phosphate occurrences on the Fort Hall Indian Reservation, Idaho (modified from Service, 1966).